

BBC

HUBBLE'S TOP 10 DISCOVERIES

25 years of amazing observation p31



ASIA EDITION

Vol. 7 Issue 7

Knowledge

SCIENCE • HISTORY • NATURE • FOR THE CURIOUS MIND

INCORPORATING

SCIENCE
WORLD

DEADLY MEGA ERUPTION

It killed thousands and cooled the planet.
Is it about to happen again? p40

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- How does a virus mutate so quickly? p85



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SCIENCE



31 Hubble's Top 10 Discoveries

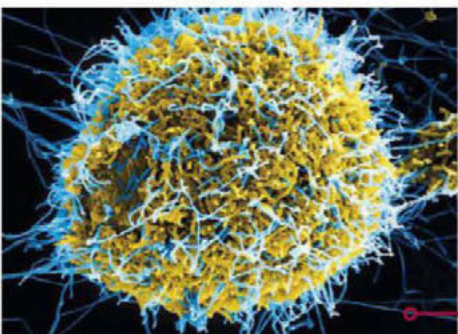


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CHALLENGED TO THINK

Recently we held the 5th edition of the BBC Knowledge Magazine School Challenge, for those who have no idea what the challenge entails allow me to explain.

Open to all secondary school students in Singapore, the School Challenge is an educational project organized by the BBC Knowledge Magazine team with the aim to provide an additional platform for learning, through stimulating the students' thinking process and encourage their natural sense of curiosity.

Divided into two days the challenge is no walk in the park. On day one, students were given only an hour to complete 50 multiple-choice questions as well as a short essay question based

on topics from history, nature and science. Those who made it through to day two will then have less than 24 hours to prepare and make a presentation to a panel of judges on a variety of topics that range from ethical issues to environmental concerns. As with previous years, the presentations were all commendable with a few stellar standouts.

To those who made it through and won, congratulations! And to those who didn't, fret not as we look forward to seeing you again at next year's BBC Knowledge Magazine School Challenge!

Ben Poon
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Experts in this issue...



Amy Tyndall

Amy has a doctorate in astrophysics and works for the European Southern Observatory. On p31 she reveals the 10 most important discoveries made by Hubble.



Bill McGuire

Volcanologist Bill is an emeritus professor at University College London. On p40, he writes about the Tambora volcano and tells us when a similar eruption could occur.



Katherine Nightingale

Katherine is a science writer at the Medical Research Council and has an MSc in molecular biology. She explains how scientists are replicating life in computers on p53.



Knowledge

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Snapshot

Hanging around

The tether attached to this NASA-developed GL-10 unmanned drone gives it away as a prototype. Nicknamed 'Greased Lightning', the plane has a wingspan of 6 metres (20 feet), can fly at speeds of up to 48km/h (30mph) and is so energy efficient that it can remain airborne for up to 24 hours.

As shown here, the craft's wings tilt vertically upwards like a helicopter during take off and landing. Once in the air, the wings swivel forward and it flies like a conventional plane. The GL-10 uses only a quarter of the energy of a helicopter and is four times more

aerodynamically efficient. Each of the 10 propellers is driven by its own electric motor, while two diesel engines charge their batteries.

"Greased Lightning is intended for civilian applications. But clearly an aircraft that can take off and land vertically, and fly efficiently, has many military and intelligence applications as well," says NASA's William J Fredericks. "Uses for this design range from the efficient delivery of small packages up to a personal air vehicle big enough to carry two people."

PHOTO: NASA LANGLEY









Sparkling water

This eerie glow is caused by a bloom of bioluminescent single-celled organisms called *Noctiluca scintillans*. They only shimmer when disturbed, which is why their light is visible in these waves hitting Hong Kong's shoreline.

"It's a light-producing chemical reaction involving the enzyme luciferase and the substrate luciferin," says Prof Keith Davidson of the Scottish Association for Marine Science. "The benefit of such bioluminescence is not clear, but may be related to attracting prey or deterring predators."

Fertilisers, containing nitrogen and phosphorus, are often washed into the sea from nearby farms, causing *N. scintillans* to bloom. While it is not toxic by itself, it excretes ammonia into the seawater. Ammonia irritates fish and inflames their gills, so they avoid areas where the glowing blooms occur.

PHOTO: PRESS ASSOCIATION

NASA celebrates 50 years of spacewalking

In this Feb. 7, 1984 photograph taken by his fellow crewmembers aboard the Earth-orbiting Space Shuttle Challenger on the STS-41B mission, NASA astronaut Bruce McCandless II approaches his maximum distance from the vehicle. McCandless became the first astronaut to manoeuvre about in space untethered, during this first “field” tryout of a nitrogen-propelled, hand-controlled backpack device called the Manned Manoeuvring Unit (MMU).

For 50 years, NASA has been “suited up” for spacewalking. The first American to conduct a spacewalk, astronaut Edward H. White II, floated into the vastness of space on the Gemini IV mission on June 3, 1965. For more than 20 minutes, White manoeuvred himself around the Gemini spacecraft as it travelled from over Hawaii to the Gulf of Mexico,

making his orbital stroll 6,500 miles long. Since this historic first, NASA astronauts have performed spacewalks, or extravehicular activity (EVA) in NASA-speak, on the Gemini, Apollo, Skylab, Space Shuttle and International Space Station programs.

A total of 166 hours of spacewalks were carried out to service the Hubble Space Telescope. Today, NASA is developing new advanced spacesuits for use by astronauts as they travel to new deep-space locations on the journey to Mars. The next-generation suit will incorporate a number of technology advances to shorten preparation time, improve safety and boost astronaut capabilities during spacewalks and surface activities.

PHOTO: NASA

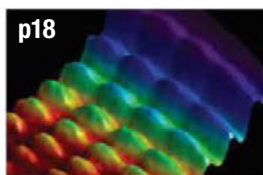






COULD TITAN HOST LIFE?

Saturn's largest moon could theoretically support life in its methane seas



LANDMARK LIGHT IMAGE

Light has been pictured behaving as both a wave and a particle



BAD LUCK, MUM

New research suggests kids are more like their fathers

THE BIG STORY

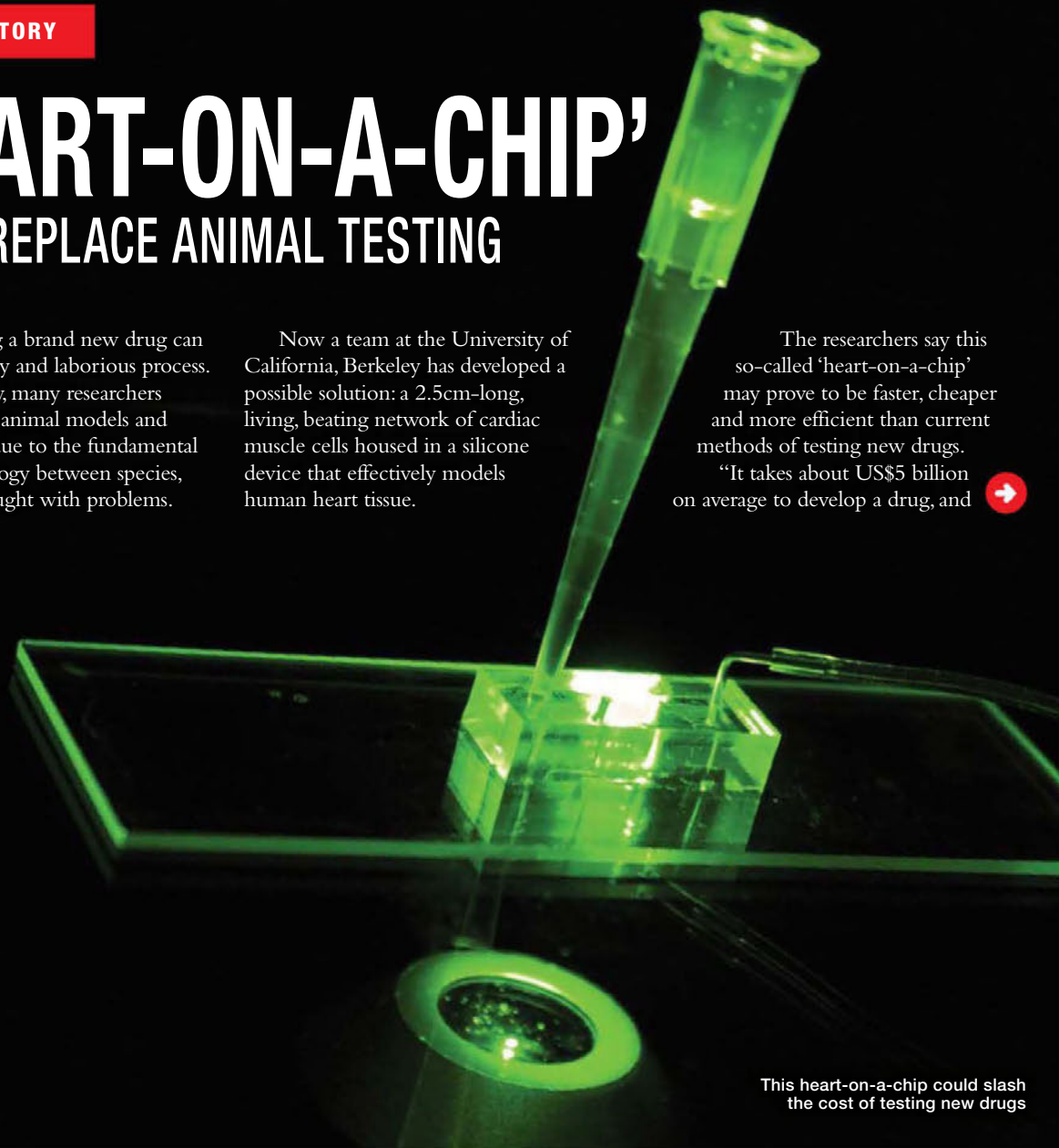
'HEART-ON-A-CHIP'

COULD REPLACE ANIMAL TESTING

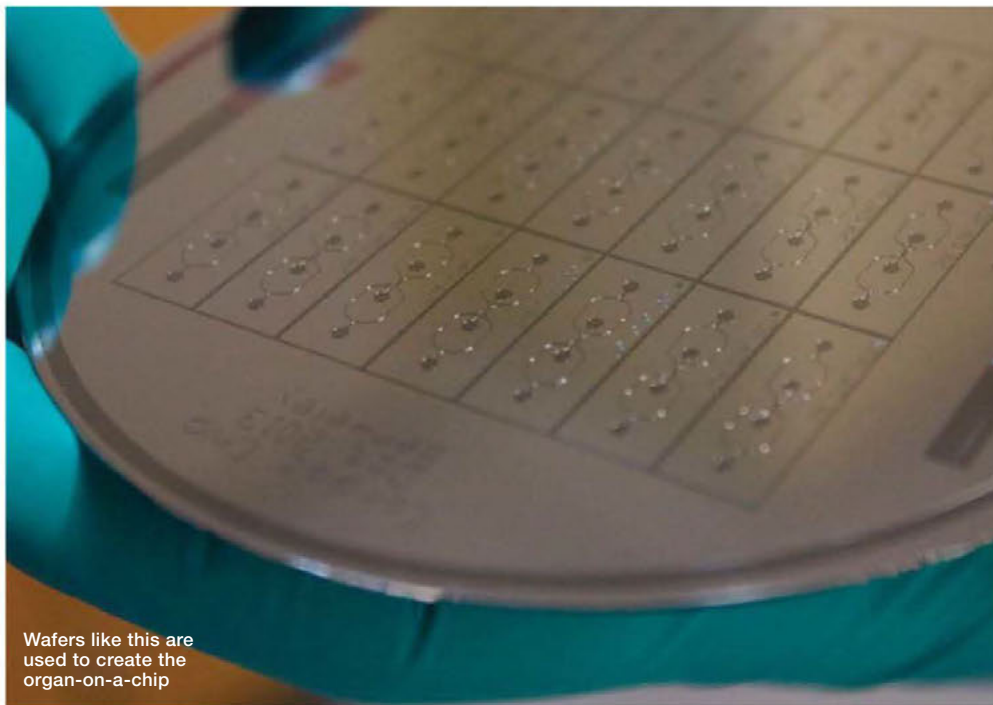
Developing a brand new drug can be a costly and laborious process. Currently, many researchers rely on the use of animal models and animal cells. But due to the fundamental differences in biology between species, this method is fraught with problems.

Now a team at the University of California, Berkeley has developed a possible solution: a 2.5cm-long, living, beating network of cardiac muscle cells housed in a silicone device that effectively models human heart tissue.

The researchers say this so-called 'heart-on-a-chip' may prove to be faster, cheaper and more efficient than current methods of testing new drugs. "It takes about US\$5 billion on average to develop a drug, and



This heart-on-a-chip could slash the cost of testing new drugs



Wafers like this are used to create the organ-on-a-chip

➔ 60 per cent of that figure comes from upfront research and development costs,” says researcher Kevin Healy. “Using a model of a human organ could significantly cut the cost and time of bringing a new drug to market. Ultimately, these chips could also replace the use of animals to screen drugs for safety and efficacy.”

The heart cells were made using human-induced pluripotent stem cells – cells that can be manipulated to grow into different types of tissue. These were loaded into a 3D model made from silicone and designed to imitate the structure of tissue fibres in the human heart. Tiny channels on either side of the cell act as blood vessels, mimicking the exchange of nutrients and drugs with human tissue.

Within 24 hours of being loaded into the chamber, the heart cells began beating on

their own at a normal rate of 55 to 80 beats per minute.

The team then tested the system using four well-known cardiovascular drugs – isoproterenol, E-4031, verapamil and metoprolol – and found that the effects on the heart tissue’s beat rate were consistent with those seen in normal human adults. The heart-on-a-chip remained functional over several weeks, meaning that it could be used to test different drugs over its lifetime.

“This system is not a simple cell culture,” says lead author Anurag Mathur. “We designed it so that it is dynamic; it replicates how tissue in our bodies actually gets exposed to nutrients and drugs.”

In the future, the system could be adapted to model human genetic diseases or even multiple organs, the researchers say.

Watch the model heart beating on YouTube at <http://bit.ly/1CIYMDy>

GOOD MONTH/ BAD MONTH

It's been good for: THOSE WITH A SENSE OF PURPOSE

Do you spring out of bed in the morning, excited about all the possibilities the day will bring? If so, lucky you – a study at Mount Sinai Medical Center has found that those with a strong sense of direction and a feeling that life is worth living are 23 per cent less likely to die from all causes than listless counterparts.

MODERATE DRINKERS



If you are on the hunt for a new partner, drinking a moderate amount of alcohol may help. Imbibing one 250ml glass

of wine made the drinker appear more attractive, according to a University of Bristol study. It is thought the effect is due to small changes in appearance such as facial flushing.

It's been bad for:

HIPSTERS



Anyone under the impression that their topknot, sailor tattoos and ironic facial hair are an outward expression of their

individuality might want to think again. Mathematician Paul Smaldino has created a model that shows that even if we try to be different, human behaviour always tends towards ‘collective conformity’. It’s why hipsters inevitably all end up looking the same, he says.

THE SHORT-TEMPERED

If you have a short fuse, there’s more reason than ever to consider new ways of calming down. The risk of a heart attack can be up to eight times higher in the two hours following an intense burst of anger, a study at the University of Sydney has found.



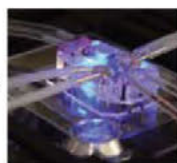
Timeline

A history of ‘organ-on-a-chip’ research

1999 2011 2013 2015

Cornell University’s Michael Shuler coins the term ‘animal-on-a-chip’ to describe his system of growing cells inside a chambered structure.

Dongun Huh from Wyss Institute for Biologically Inspired Engineering creates a lung-on-a-chip (pictured, right) using a polymer membrane lined with human lung cells.



A team at the Wake Forest Institute for Regenerative Medicine in North Carolina manages to 3D bioprint a heart, a liver, a lung and blood vessels.

Mark Donowitz at Johns Hopkins University begins work on a gut-on-a-chip by growing intestine cells with the aim of creating a functioning organ.

SPACE

Life without water on Saturn's moon?



As water played a key role in the development of all life on Earth, the search for life on other planets has largely looked for the presence of liquid H₂O. But perhaps life can arise in other environments.

This was the starting point for chemical engineers from Cornell University, who designed the azotosome: a hypothetical cell membrane that could survive in the harsh, cold, methane-rich world of Titan, Saturn's largest moon.

Cell membranes are found in every living thing and protect the inside of cells from the outside world. They

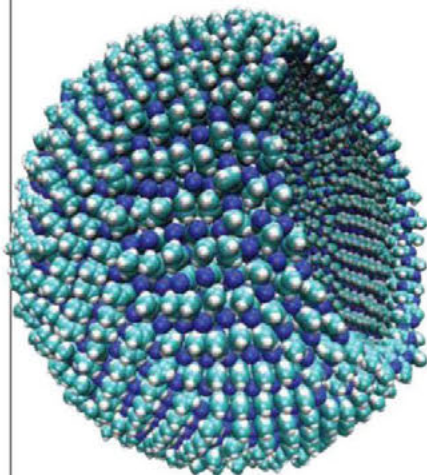
do this by allowing certain substances through and blocking others. It is a process essential for life. Without it, the necessary chemical reactions would be unable to take place.

On Earth, cell membranes are made from a permeable substance known as the phospholipid bilayer and they exist in environments that contain water. In order to look for a potential methane-based equivalent, the team looked for compounds made from carbon, nitrogen and hydrogen. These elements are known to exist in the methane seas on Titan and are capable of self-assembling into membrane-like structures.

They found a match in acrylonitrile, which is present in Titan's atmosphere. It is a colourless, poisonous, organic compound used to make acrylic fibres and plastics on Earth.

"We're not biologists and we're not astronomers, but we had the right tools," says study leader Paulette Clancy. "Perhaps it helped, because we didn't come in with any preconceptions about what should be in a membrane and what shouldn't. We just worked with the compounds that we knew were there."

The next step is to investigate how these membranes could harvest energy and reproduce in the methane environment.



The azotosome could survive without H₂O

PHOTO: JAMES STEVENSON/CORNELL UNIVERSITY PHOTOGRAPHY X2



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New websites, blogs and podcasts



SPACEPROB.ES

<http://spaceprob.es>

There are currently 29 space probes out in the cosmos, and they're all listed on this website –

including everyone's favourite Mars rover, Curiosity. You'll find summaries of what the probes are currently doing, along with some well-curated links if you want to find out even more.

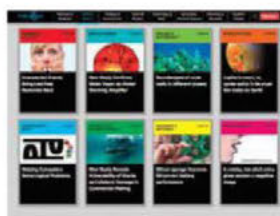


OCEARCH

oearch.org

If sharks fascinate you, then why not track them all over the world? OCEARCH is a non-profit organisation that tags

and tracks sharks. It then gives scientists access to all of the collected data, but you can take a look too. Read about how sharks are tagged and see how they move across the world's oceans.



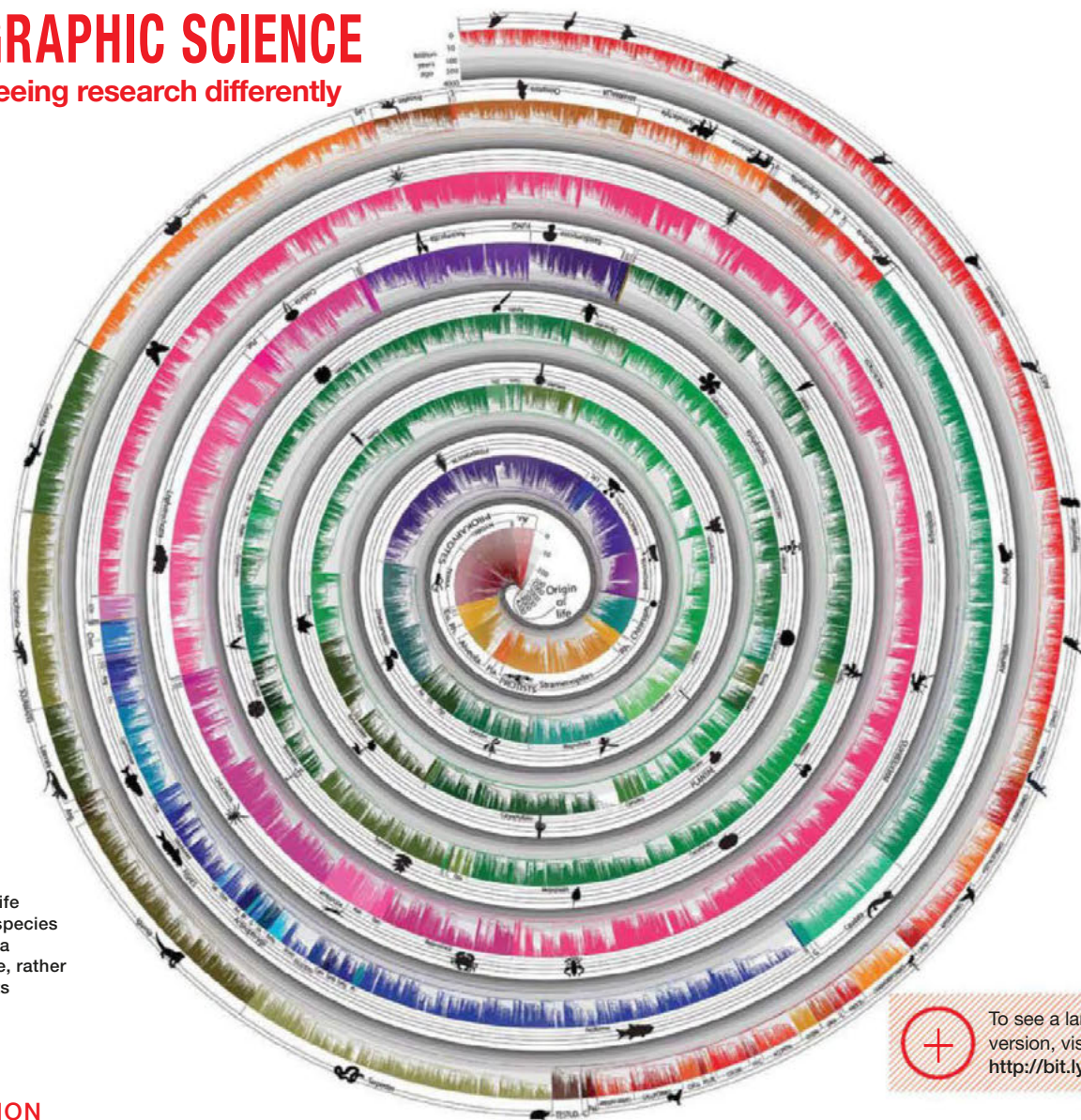
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KELLY OAKES is Science Editor at BuzzFeed. She tweets from @kahoakes



This tree of life shows new species emerging at a constant rate, rather than in bursts

To see a larger version, visit <http://bit.ly/1BQKdr9>

EVOLUTION

'Tree of life' reveals species emerge every two million years

This kaleidoscopic spiral shows the most accurate picture of the evolution of life on Earth. It was put together by researchers at Temple University in Philadelphia and details the emergence of more than 50,000 species, dating back to the origin of life itself.

The team pooled data from 2,274 studies investigating the molecular biology and genetic

evolution of various species and fed it into custom-designed computer algorithms to create this detailed picture of the tree of life. Contrary to the conventional view that species diversification is driven by adaptation, the researchers say the new tree highlights the importance of random genetic events.

As ecological niches fill with species, competition for

resources intensifies. The rise of new species might, therefore, be predicted to slow down. But the study shows a new species emerging roughly once every two million years.

"The constant rate of diversification that we have found indicates that the ecological niches of life are not being filled up and saturated," says researcher S Blair Hedges. "This is contrary

to the popular alternative model which predicts a slowing down of diversification as niches fill up with species. This finding shows that speciation [process by which new species arise] is more clock-like than people have thought."

The team plans to add more data and wants to develop new tools to allow other researchers to update the ever-growing tree.

1 MINUTE EXPERT

MOTS-c



Is that a new type of safety test for scooters?

Way off. It's a newly discovered hormone that appears to counteract some of the negative health effects caused by eating a diet that's high in fat.



Tell me more.

Hormones act as the body's signals, triggering various physiological responses. Most hormones are encoded in the DNA of the cell's nucleus, but MOTS-c is unique in that it is encoded in the DNA of mitochondria instead. Mitochondria are the powerhouses of cells that convert food into energy.



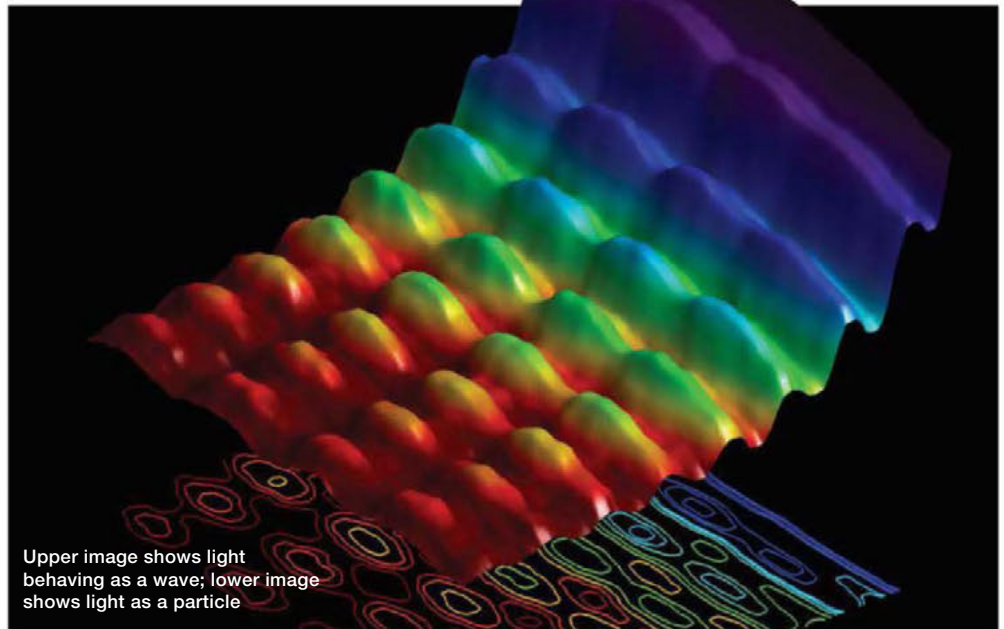
So what exactly does it do?

When the team injected MOTS-c into mice that were fed on a diet high in fat, they didn't become obese or develop insulin resistance in the same way their natural siblings did. The mechanisms involved in the effect are present in all mammals, including humans, the researchers say.



Fantastic – make mine a double cheeseburger!

Hold your horses. Human trials aren't scheduled for another three years. So stick to your healthy diet in the meantime.



Upper image shows light behaving as a wave; lower image shows light as a particle

PHYSICS

Landmark picture of light

It is one of the most famous examples of so-called 'quantum weirdness': light can act as both a particle and a wave simultaneously. Now, a research group at Switzerland's École Polytechnique Fédéral de Lausanne (EPFL) has captured the first ever snapshot of this beguiling dual behaviour by using an innovative electron-based imaging technique.

"This experiment demonstrates that, for the first time ever, we can film quantum mechanics, and its paradoxical nature, directly," says lead researcher Fabrizio Carbone.

To create the image, they fired a laser at a metallic nanowire, causing charged particles within it to vibrate. As a result, light waves moved up and down the wire in both directions and combined to form a 'standing wave' – a wave that looks like it's frozen in place. They then shot a beam of electrons at the nanowire.

When the electrons hit the photons (light particles) travelling up and down the wire, they either sped up or slowed down. Using an ultrafast microscope to record the position at which this change in speed occurred, the team was able to visualise the standing wave, revealing the wave nature of light. As the change in speed appears as an exchange of packets of energy known as 'quanta' between the electrons and the photons, light is simultaneously seen to behave like a particle.

"The ability to directly image quantum mechanical effects, and control them via light pulses, opens new possibilities," says Carbone. "For example, one may engineer circuits that function as we imaged in this work, and exploit their quantum properties to create advanced logic gates or similar exotic devices."

WHO'S IN THE NEWS?

Sergio Canavero

Italian surgeon



Who's he and what has he done?

Sergio Canavero is based at the Turin Advanced Neuromodulation Group in Italy. Canavero has published a paper detailing a technique he says could be used to graft a living person's head onto the body of a donor. What's more, he says it could happen in as little as two years.

What?! How is he going to do that?

The technique involves cooling the head and body to increase the time that cells can live without oxygen. After cutting through the neck, the blood vessels and spinal cords will be joined together using special chemicals. The patient will then be put in an induced coma for a month while they heal.

Right. Well, that sounds easy enough...

Not quite. A number of critics have hit out at Canavero, saying there is no evidence that simply connecting the spinal cord to the brain will allow the patient to successfully control the donor body. There are also, of course, some serious ethical questions that such an extreme procedure would raise.

New syringes will make injections safer

DAVID SHUKMAN
The science that matters



You have a headache, but you do not reach for a tablet. Instead, you opt for something you are convinced is more effective: an injection.

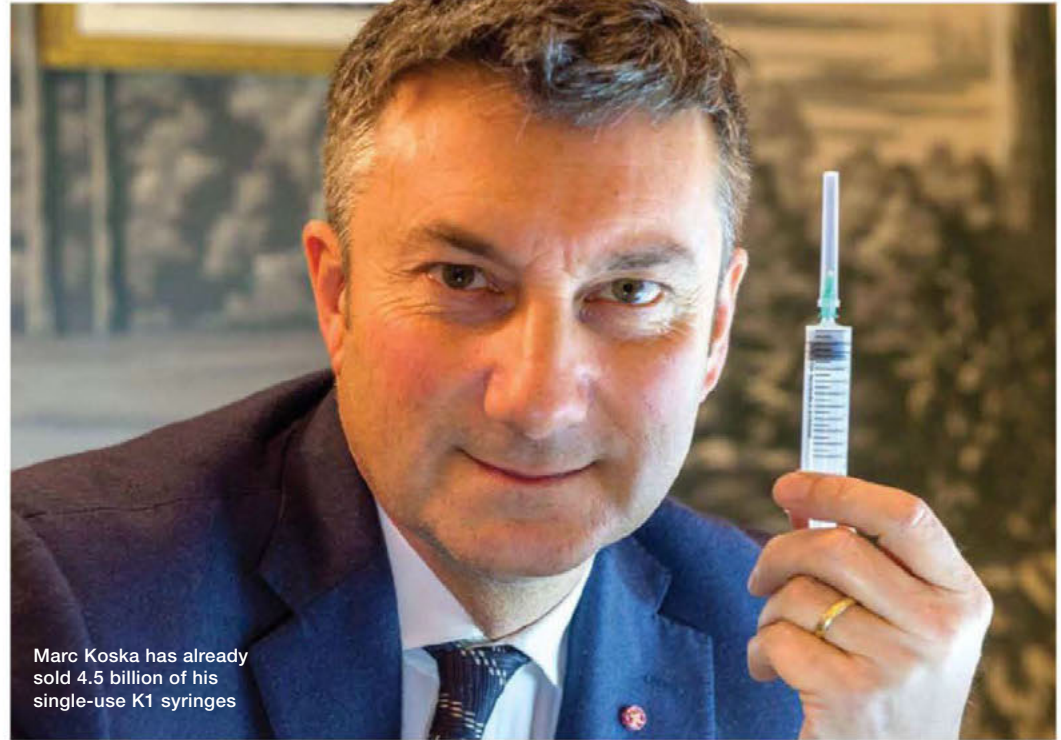
That is the case in many of the poorest countries, where equipment such as a syringe attached to a needle is seen as more useful than some little pill from a packet. The promise of medical technology exerts a powerful lure.

Most of us would do almost anything to avoid injections. But around the world, some 16 billion jabs are administered every year, and often to people who obviously do not understand the risks.

I saw this for myself in Cambodia recently. The remote village of Roka, a quiet community of rice farmers, is in the grip of an outbreak of HIV. At the time of writing, more than 270 people were infected and five had died.

The common factor was that they had been given injections with reused syringes. An unlicensed medic had administered the jabs, passing the HIV from one to another, and he is now in custody facing murder charges.

So a simple piece of medical equipment, which must have saved



Marc Koska has already sold 4.5 billion of his single-use K1 syringes

countless lives since it started to be mass-produced in the last century, can be a killer in the wrong hands.

The problem is that even if the self-styled medic had tried to sterilise the equipment between each use, it's almost impossible to be sure of killing off every bug or virus. The safest solution is a syringe that can only be used once. And that is exactly what British inventor Marc Koska has designed.

His K1 syringe, which has earned him awards, has a feature that means it 'auto-disables' if someone tries to refill it. I had a go myself: as you draw back the handle of the plunger, there's a click as it snaps off.

Now that the costs of these 'smart' syringes broadly match those of normal ones, there is a real chance that they will catch on. The World Health

Organization has told the manufacturers and big donors that it wants the syringes to become standard by 2020.

That may be optimistic. But next time I'm having an jab, I'll be paying a lot more attention.

DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc

THEY DID WHAT?! Music composed for cats

What did they do?

David Teie, a composer at the University of Maryland, wrote a piece of music specifically for cats. It was based on rhythms that mimic the cadence of

purring and the suckling rates of kittens, and sliding tones modelled after cat vocalisations.

What did they find?

The cats approached and rubbed themselves on the loudspeakers much more when they heard the feline compositions than when they were played Bach's *Air On The G String* and



Fauré's *Élégie*, which are both pieces that humans find relaxing. They also responded more quickly after hearing the cat-based music.

Why did they do it?

The results suggest that music could be composed for other species, which could be used to calm animals being kept in zoos or shelters. Listen in at musicforcats.com



PATENTLY OBVIOUS

with James Lloyd

Inventions and discoveries that will change the world



Say cheerio to BO

When you're going on a date or an all-important business trip, the last thing you want is a BO (body odour) problem. After all, no one wants to sit next to someone who smells like a skunk's squash kit. Thankfully, Google is on the case. Its 'odour-removing device' monitors your body temperature, heart rate, sweat levels and other statistics so that it knows when you're working out or feeling stressed. If it thinks you're likely to pong, the device sprays out a perfume to counteract your funky fragrance.

The device would be able to store information such as your sweat history, exercise schedule and appointment calendar so that it knows when you're likely to need perfuming again. It might even use social networks to track the location of your contacts, suggesting an alternative route so that you can avoid subjecting them to your unpleasant whiff. Patent number: US 8,950,238

Invisible ink

As many as one in three people regret their tattoos, so removing unwanted body art is big business. Usually, lasers break down the ink in a painful and expensive process. But a PhD student at Dalhousie University has developed a cheap, painless alternative. Alec Falkenham's tattoo removal cream targets the cells, or 'macrophages', that swallow the pigment when the tattoo is originally formed. Agents in the cream encourage new macrophages to gobble up the old, ink-filled ones, resulting in a tattoo that gradually fades away.

Patent pending

Inner-city crops

Are you a city dweller who wants to grow fruit and veg? Well here's one for you. My Terrace Farmer is a solar-powered greenhouse that's small enough to fit in a tiny backyard or a balcony. Developed by Colorado's Solar Greens Company, the greenhouse is portable, can be assembled in an afternoon, collects rainwater and creates its own compost. Best of all, the Garden Genie add-on automatically waters and lights your plants when it's needed, monitoring temperature and soil humidity so that you don't have to.

Patent pending

GENETICS

Mammals are more like their fathers

The phrase 'like father, like son' may have to be updated to include daughters. According to a study on lab mice at the University of North Carolina, mammals are more like their dads than their mums.

Although we inherit equal amounts of genetic mutations from each parent, the study says that mammals use more DNA from the dad. Mutations handed down from parents show up in many common but complex diseases that involve multiple genes, such as heart disease, schizophrenia and cancer, so

studying them may shed light on mechanisms involved.

To find the effect, the team selected three genetically diverse strains of mice and bred them to create nine different types of offspring in which each strain was used as both father and mother. When the mice reached adulthood, the team measured gene expression in four different types of tissue, including in the brain. The researchers then calculated how much gene expression was derived from the mum and the dad for every gene in the genome. Gene expression is



There was plenty of water on Mars four billion years ago, when it could have supported life



SPACE

Mars was home to a giant ocean

Before it became the barren Red Planet, a vast ocean covered 20 per cent of the surface of

Mars, NASA scientists have found. The discovery means it may have remained habitable for longer than previously thought.

About four billion years ago, the young planet held around 20 billion cubic km of water, which is enough to cover its entire surface to a depth of 140m. However, it is likely that the liquid pooled to form a vast ocean covering almost half of the northern hemisphere, the researchers say.

The findings come from an international collaboration involving the Very Large Telescope, the Keck II telescope and the NASA Infrared Telescope Facility. They are based on measurements of the amount of HDO – a heavier form of water found on Mars.

“I am again overwhelmed by how much

power there is in remote sensing on other planets using astronomical telescopes,” says researcher Ulli Kaeufl. “We found an ancient ocean more than 100 million kilometres away.”

Due to its heavier weight, less HDO is lost to space than regular water. This means that the greater the water loss from a planet, the greater the ratio of HDO to regular H₂O in the water that remains.

By comparing the ratio of HDO to H₂O in water on Mars today and comparing it to water trapped in a 4.5 billion-year-old Martian meteorite, the team could estimate how much water has escaped into space.

“With Mars losing that much water, the planet was very likely wet for a longer period of time than previously thought, suggesting it might have been habitable for longer,” explains researcher Dr Michael Mumma.

crucial for human health and links DNA to proteins, allowing them to carry out various functions inside cells.

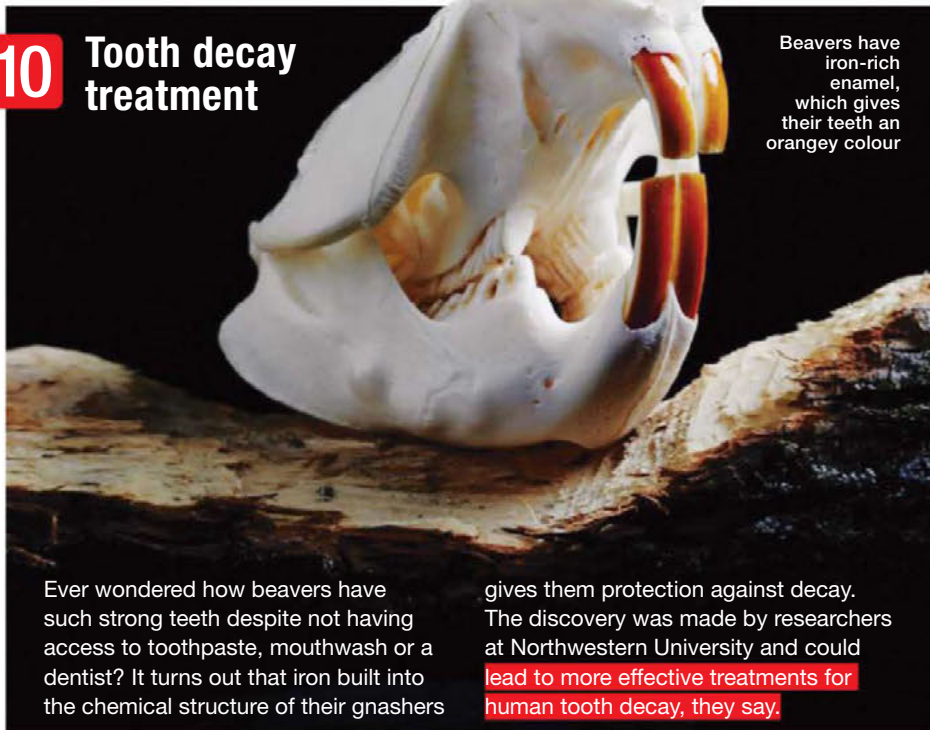
“This expression level is dependent on the mother or the father,” says senior author Pardo-Manuel de Villena. “We now know that mammals express more genetic variance from the father. Imagine that a certain kind of mutation is bad. If inherited from the mother, the gene wouldn’t be expressed as much as it would be if it were inherited from the father. So the same bad mutation would have different consequences in diseases that were inherited from the mother or from the father.”



“Aw, she looks just like her dad!”

10 DISCOVERIES THAT WILL SHAPE THE FUTURE

10 Tooth decay treatment



Beavers have iron-rich enamel, which gives their teeth an orangey colour

Ever wondered how beavers have such strong teeth despite not having access to toothpaste, mouthwash or a dentist? It turns out that iron built into the chemical structure of their gnashers

gives them protection against decay. The discovery was made by researchers at Northwestern University and could lead to more effective treatments for human tooth decay, they say.

9 Pollution-busting flags

Here's a breakthrough that is really flying the flag for green technology. Literally. Scientists at The University of Sheffield have coated advertising flags with a catalytic solution that removes harmful nitrogen oxide from the air. They hope the technology could soon be used to help reduce traffic emissions at petrol stations.



8 Power from pee

A toilet has been designed that can generate power from urine. The system, which has been produced by the University of the West of England and Oxfam, is based on a fuel cell that uses live microbes. These feed on urine and convert it into electricity. It is hoped the tech can be used to power lighting in refugee camps.



The toilet prototype is available to use at UWE

7 Leg muscle grown in laboratory

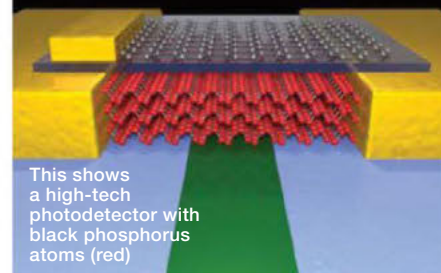


The researchers want to try creating lab-grown muscle for larger animals than mice

You may no longer have to spend hours in the gym squatting to get thighs like Sir Chris Hoy. Scientists have grown a functioning leg muscle from engineered cells cultured in a dish and successfully grafted it onto a mouse. The method could allow for patient-specific treatments for a large number of muscle disorders, they say.

6 Wonder material to speed up internet

Move over graphene, there's a new wonder material on the block. Black phosphorus, a crystalline form of the stuff used in match heads, could be used in ultra-fast communications. A team at the University of Minnesota has built a system that sends optical data at speeds of three billion bits per second, equivalent to downloading an HD movie in 30 seconds.



This shows a high-tech photodetector with black phosphorus atoms (red)

5 Batteries from packaging

We've all been there. You've just had a new TV delivered and are left wondering what to do with all the packing peanuts left in the box. Now, a Purdue University team has developed a way of converting them into carbon microspheres that **can be used as anodes in rechargeable batteries**. It's a cheap process and the resulting material performed better than existing ones.

4 Solar-powered shrimp

They may taste great in a curry, but shrimps can also be turned into electricity generators. Researchers at Queen Mary University of London have created solar cells from chitin and chitosan, chemicals found in the shells of crustaceans. **They could be used in wearable chargers for tablets and phones**, or in semi-transparent films for windows, the researchers say.

This shrimp is safe – we don't eat this species



3 Self-cleaning paint

It's a window cleaner's worst nightmare: a sprayable coating that can make almost any surface clean itself. The substance was created using titanium dioxide nanoparticles by a team at UCL. **The paint**

can be applied to clothes, paper, glass and steel and even maintains its self-cleaning properties after being scratched and scuffed. It works by being extremely water-repellent.

2 Molecule making machine

Many chemicals are tricky to make in the lab, but this machine could allow simpler synthesis

It's like a 3D printer for molecules. Chemists at the University of Illinois have designed a machine to assemble complex molecules with the click of a mouse. **The process could greatly speed up drug development, they say.** The technique

works by breaking down complex molecules into smaller building blocks all with the same connector piece. They can then be joined together with one simple reaction in a manner similar to children's building blocks.

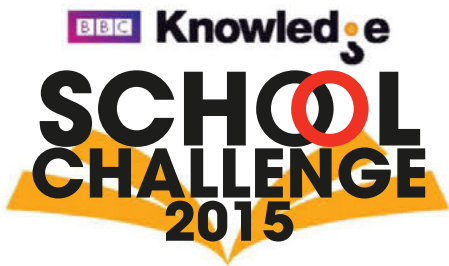
1 Noise-cancelling windows

If you have loud neighbours, this may be just what you need: **double-glazed windows that block out noise**. Created at Mokpo National Maritime University, South Korea, the technology uses an array of resonance chambers that trap sound waves. The waves bounce around and eventually cancel one another out.



The windows can block traffic noise, screaming..

BBC Knowledge Magazin



Every couple of years there is a renewal of sorts at the BBC Knowledge Magazine School Challenge, this year's edition saw many new faces as the graduating secondary school students made way for a generally younger cohort of participants.

As with past editions, this year saw an overwhelming number of entries and from a wider range of secondary schools as well. Now into its 5th year, the two day BBC Knowledge Magazine School Challenge has hardly gotten any easier, this according to participants who had tried multiple times to enter and hopefully win since they were in lower secondary. The tough 50 multiple-choice questions plus a short essay question on day one (held at the Singapore Discovery Centre this year) are always based on topics ranging from nature, science and history. Participants have to read widely and pay close attention to current issues affecting the world in order to comprehend and then to answer the questions correctly.

For those who made it through to day two (held at the S.E.A Aquarium of Resorts World Sentosa), from the moment they received their presentation topics, it marked the beginning of an intense rush to adequately research, prepare a fluent, factual yet entertaining presentation in less than 24 hours. Almost impossible, yet for some teams such as the winners from Raffles Girl's School, they proved it wasn't an insurmountable task..



Scan this QR Code to view the photos for Day 1



e School Challenge 2015



All participants will receive a personalised certificate each

BBC Knowledge Magazin



Scan this QR Code to view
the photos for Day 2

Participating Schools

Anglo - Chinese School (Independent)
Bukit Panjang Government High School
Catholic High School
Cedar Girls Secondary School
CHIJ St Nicholas Girls' School
Clementi Town Secondary School
Damai Secondary School
Dunman High School
Hwa Chong Institution (High School)
Methodist Girls School
Nanyang Girls' High School
NUS High School
Raffles Girls' School
River Valley High School
School of Science and Technology Singapore
Singapore Chinese Girls' School
St Joseph's Institution
Tanjong Katong Girls' School
Xinmin Secondary School

*Regent Media would like to thank all
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participation and support of the BBC
Knowledge Magazine School Challenge 2015.*



Ms Esther Tang, Voiceworks
with Mr Arthur Tay, Executive Director, Regent Media



Mr Daniel Heath, Director of Sales and Marketing, S'pore Discovery Centre
with Mr Arthur Tay, Executive Director, Regent Media



Mr Alan Tan, Managing Director, Urban Palette Pte Ltd
with Mr Arthur Tay, Executive Director, Regent Media



e School Challenge 2015



1st Raffles Girls' School - Deanna See Xuhui, Chloe Young, Christine Chiang, Swathi Nachia Manivannan



2nd Nanyang Girls' High School - Ng Jia Ling Jerlyn, Ong Yan Lin, Cheyenne, Phua Jue Yu, Sharmaine Koh Mingli



Ms Sara Pek, Project Manager, National Library Board with Mr Arthur Tay, Executive Director, Regent Media



3rd Catholic High School - Lhui Kay Kin Clyde, Luke Chan Teng Guan, Lew Tee Hean Justin, Wee Song Wen Lucas



4th Hwa Chong Institution (High School) - Gui Ming Jiang, Tan Wei Chuan, Silas Yeo Shuen Yu, Robert Wang Hao Jia



Mr Marcus Chew, Senior Executive Education Operations, Resorts World Sentosa with Mr Arthur Tay, Executive Director, Regent Media



5th Hwa Chong Institution (High School) - Ernest Ng Wei Jun, Mak Wei Jie Alvern, Daniel Lim Yu Hian, Tan Te Juan



6th School of Science & Technology Singapore - Yong Zhi Jie David, Ian Lee Zi Xu, Ramanathan Kumarappan, Koh Li Zhi Walter



Mr Robert Playfair, Head of Secondary, English for Schools, British Council with Mr Arthur Tay, Executive Director, Regent Media



7th Dunman High School - Liew Soon Hao, Lo Yong Ern Matthew, Nicole Sim Jiaxuan, Sim Rou Chen



8th Catholic High School - Daryl Tan Zhe Han, Ng Yoon Yik, Phua Wei An, Teo Jun Hua



Coach Firoze, Voiceworks with Mr Arthur Tay, Executive Director, Regent Media

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	<input type="radio"/> 41 - 50	<input type="radio"/> Professional	<input type="radio"/> \$100,001 - \$150,000
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Comment & Analysis

Walking on ‘thin air’ is unnerving, but helps us understand how light works

An exuberant toddler gallops happily across the rectangle and pauses in the middle for some exploratory jumping before his dad ushers him away. A young couple refuse to venture across it and instead sit nervously at the edge, taking selfies with the rectangle in the background. What’s weird is that it’s only a footbridge, and there’s nothing really unusual about the rectangle in the middle. It’s made of perfectly robust material, just like the rest of the bridge. It’s just that visible light happens to pass straight through it.

I’m standing on the walkway across the top of Tower Bridge in London, looking down through the glass floor to the road and the river below. I can stand with one foot on the glass and one foot on the metal beside it. Atoms hold up one foot, and atoms hold up the other foot. But standing on one side of that line is scary. Is that justified?

We assume that ‘stuff’ should interfere with light, and so it seems obvious that we can see it. But the more interesting question is: why does matter bother light at all? After all, we know that atoms are mostly free space, each one a tiny dense nucleus chaperoned by a sprinkling of distant electrons. There’s loads of space for a passing light ray to zoom right through, and lots of them do. As I walk through the sightseers on the bridge, radio waves and Wi-Fi signals are whooshing straight through me. When you consider the entire electromagnetic spectrum, I’m almost completely see-through. There’s just this funny little bit in the middle where that’s not true, and it gives us all the visual richness we take for granted.

I can see Tower Bridge for two reasons. One is that my eyes only see photons that have the right energy to play bumper cars with the electrons in most materials. Light is absorbed and reflected as the electrons get shuffled around, and that only happens at a very narrow range of wavelengths – the visible part of the spectrum. The second reason is that if a light wave meets an obstacle that’s about the same size as its wavelength, it’s likely to be deflected. The small-scale structure of the object can make it visible, whatever substance it is made of.

The bouncing toddler knows none of this. But he is perfectly safe. It just so happens that

“When they build the first completely transparent building, I will be up there, jumping with glee like the toddler”

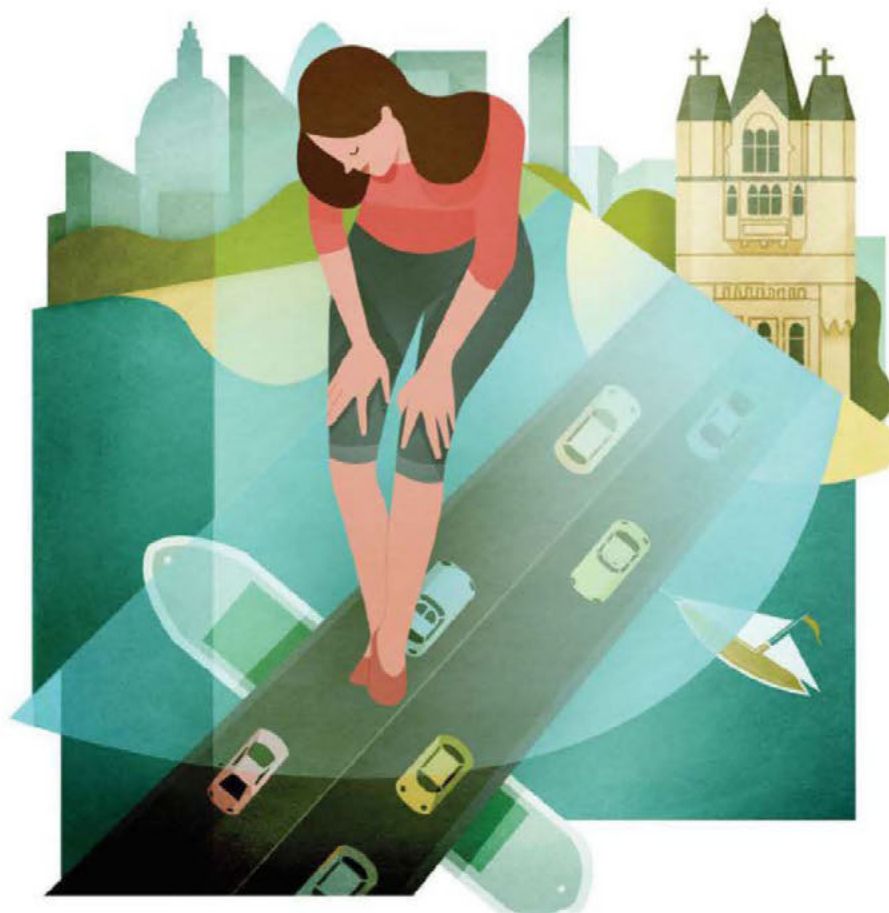
those two reasons don’t apply to glass and they’re not directly related to its strength. The atoms in glass are jumbled up without any regular structure. This changes the energy that’s needed to shuffle electrons, so that instead of absorbing visible light, glass absorbs the more energetic UV light. Visible light goes straight through, because there’s no reason for it not to. And because of the fluid-like structure of the atoms, there are no

boundaries or pores or cracks in the glass, so light doesn’t get scattered either.


Standing on the glass walkway, looking down, I can actually see that this is a flawless material. You’d think that might be more reassuring than standing on an opaque one, without any clues to its structural integrity. The expression on the face of one woman edging around the glass while trying not to look down suggests that this is not the case.

The illusion of walking on nothing is unnerving. But it’s also a lot of fun because it reminds us to ask why we can see anything, and what our sight is really telling us. When they eventually build the first completely transparent building, I will be up there, jumping with glee like the toddler, and admiring a new view of our world. ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series was *Super Senses*



HUBBLE'S TOP 10 DISCOVERIES



The Hubble Space Telescope has been observing the Universe for a quarter of a century. Amy Tyndall takes a look at some of its most incredible discoveries

Twenty-five years ago, one of the most famous and awe-inspiring pieces of technology – The Hubble Space Telescope – was launched.

Hitching a ride with the Space Shuttle Discovery in 1990, Hubble was placed in low-Earth orbit, where it has been continuously observing the night sky ever since. Observations have been carried out across all wavelengths of light, from ultraviolet to infrared, which have given astronomers an unprecedented window on the Universe.

But what have they learned from its breathtaking pictures? To find out, we polled 100 professional astronomers around the world, and the results are in...



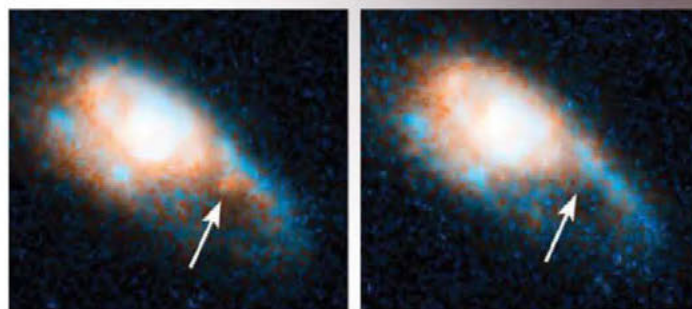
10

CAUSE OF GAMMA-RAY BURSTS

The fuzzy-looking galaxy to the right was home to one of the most energetic events in the Universe: a gamma-ray burst (GRB). These flashes of gamma-ray radiation are an enigma because they're so rare – a typical galaxy produces only a few every million years. Yet they release as much energy in a few seconds as our Sun does in 10 billion years. On 3 June 2013, a GRB lasting one-tenth of a second occurred, and was spotted by NASA's Swift satellite. When Hubble looked 10 days later, it found an infrared glow where the burst had been. But by 3 July it had faded. This disappearing glow was the dying embers of another kind of cosmic explosion – a kilonova – believed to be the result of extremely dense stars called 'neutron stars' merging. Since the kilonova was found in the same location as the GRB, it was the 'smoking gun' revealing that short GRBs could well be caused in the same way. The kilonova was investigated by Prof Nial Tanvir of Leicester University, who says Hubble played a vital role. "Although Swift discovered this particular short gamma-ray burst, and observations from ground-based telescopes gave us its precise position and distance, Hubble was the only option for seeing the faint kilonova emission."

"Gamma-ray bursts release as much energy in a few seconds as our Sun does in 10 billion years"

① An infrared glow was spotted on 13 June 2013 (left) but had faded by 3 July (right)



HOW PLANETARY COLLISIONS WORK

On 16 July 1994, telescopic eyes were turned on Jupiter as the first of 21 fragments of the broken-up comet, Shoemaker-Levy 9, crashed into the planet. Blotches scarred the atmosphere for a month before fading away.

Hubble's observations provided a wealth of information about Jupiter's atmosphere. "Obvious waves emanated from the largest impacts, like ripples in a pond. From this, we could make deductions about the deep atmosphere and water below the clouds," explains Dr

Amy Simon, senior scientist for planetary atmospheres research at NASA Goddard.

While ground-based observatories were also involved, Hubble was the only one that could look across an entire range of wavelengths, irrespective of the time of day or weather conditions. Ultraviolet was particularly important for imaging dust and aerosols whipped up by the impacts. "Hubble observed leftover debris and molecules high in the atmosphere for months, and even years, afterwards," says Dr Simon.

① Comet Shoemaker-Levy 9's impact (dark spots) could be seen on Jupiter

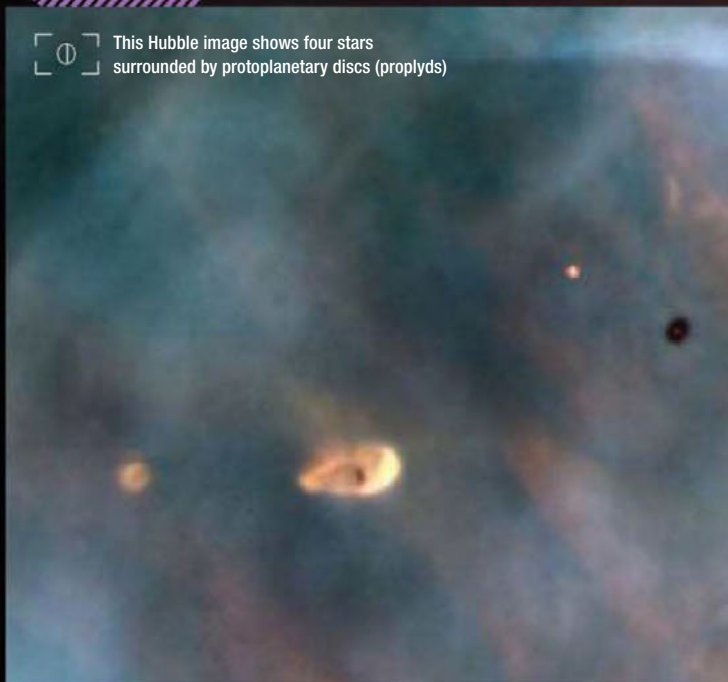


Protoplanetary discs (like the one in this artist's impression) are where planets are born. They shed light on the early Solar System

8



This Hubble image shows four stars surrounded by protoplanetary discs (proplyds)



PROTOPLANETARY DISCS

Looking like little islands, these flat discs of cold dust and gas are left over from the formation of a new star in the Orion nebula. Although part of this material will be lost over time, some will eventually clump together in pebble-sized grains before potentially building up to form a baby planet. As such, they are known as protoplanetary discs, or 'proplyds'. By learning about proplyds, astronomers hope to find out more about the formation of Earth and the other planets. "This is what our Solar System looked like in its infancy," says Prof C Robert O'Dell, who made this image. Ground-based telescopes had previously detected the objects, which were initially believed to be stars. The idea that they were discs of material surrounding the star goes back to the 1700s, but confirmation didn't come until the late 1980s, when astronomers managed to detect the disc through observations of its molecules. Hubble provided the breakthrough – directly imaging numerous proplyds for the first time within the Orion nebula.



[⊕] Hubble reveals individual stars in the galaxy M81, including Cepheid variables that were used to determine that the Universe is 13.8 billion years old

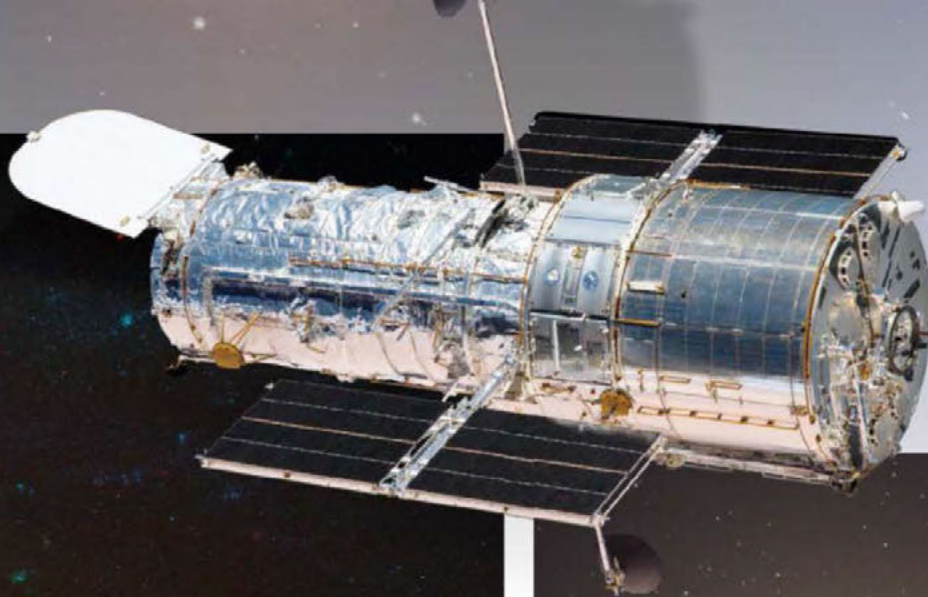
THE AGE OF THE UNIVERSE

This spiral galaxy, M81, was the first of many galaxies observed by Hubble to find the expansion rate, and therefore the age, of the Universe. "Before the launch of Hubble, there was a heated debate over whether the Universe

was 10 or 20 billion years old," says Prof Wendy Freedman, an astronomer at The University of Chicago. Freedman set out to measure Cepheid variable stars - pulsating stars, whose brightness increases and decreases over a timescale of days to months. By determining the relationship between a Cepheid's brightness and its pulsation rate, it is possible to estimate its distance.

Cepheids are the most accurate way of measuring the distances to galaxies, and for setting the expansion rate of the Universe.

The high resolution of Hubble's instruments meant that the team was able to discover over 800 Cepheids in 24 nearby galaxies. The Hubble measurements helped to determine that the age of the Universe is 13.8 billion years.



The blue stream of material is being ejected from a black hole at the centre of the M87 galaxy

**“The history of
astronomy is a history
of receding horizons”**

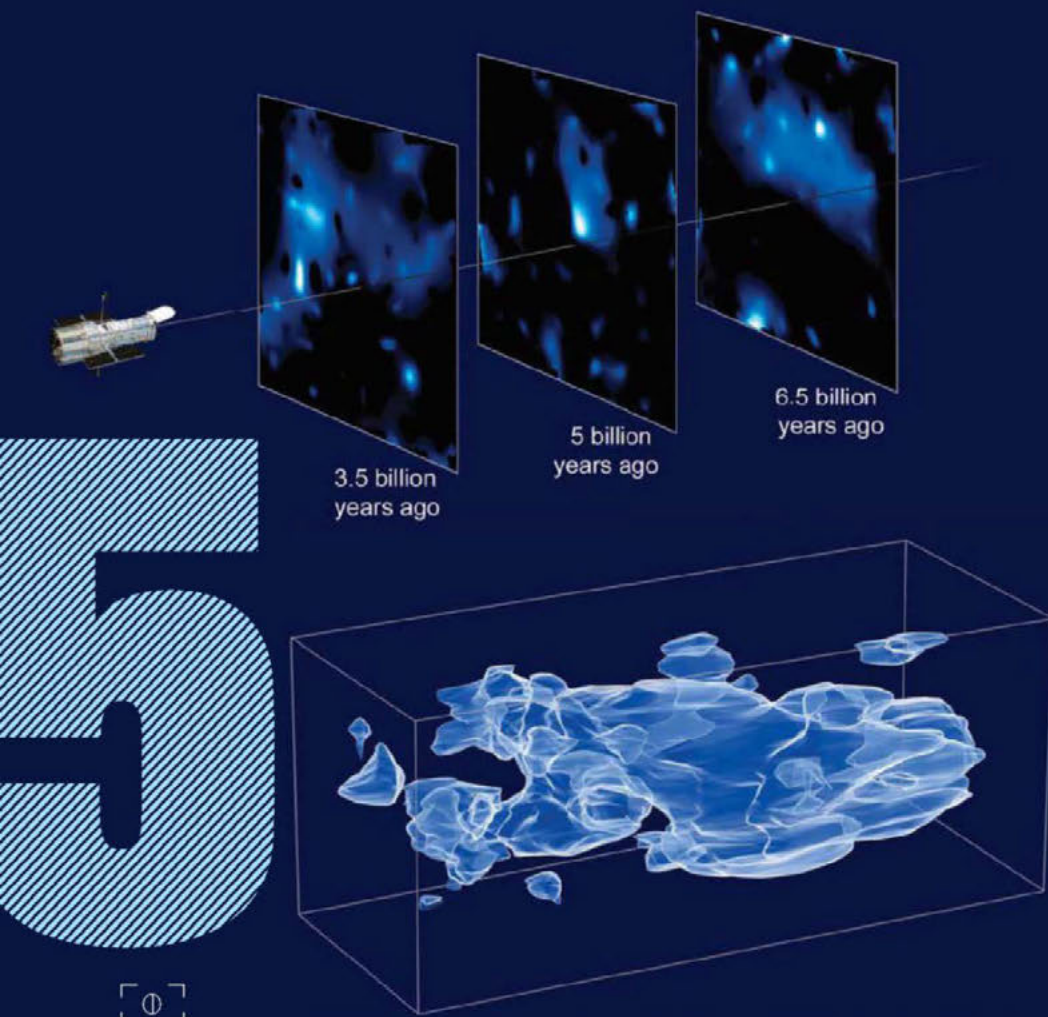
Edwin Powell Hubble, 1936

SUPERMASSIVE BLACK HOLES

Black holes are difficult to find. Their intense gravitational force is so strong that not even light can escape their pull, making them ‘invisible’. But by measuring the speed of material that surrounds a black hole, it is possible to calculate its mass using the laws of gravity. If there is more mass than is accounted for by the stars we see, the rest could be due to a black hole. By the early 1990s, it was suspected that a supermassive black hole (SMBH) was at the centre of a handful of galaxies.

“Soon after its launch, Hubble confirmed earlier SMBH detections by taking images five times sharper than those obtained from the ground,” explains Dr Marc Sarzi, an astronomer at the University of Hertfordshire. Hubble became known as a ‘black hole hunter’, due to its ability to measure the speed of surrounding gas and stars. Results from its observations were surprising, says Dr Sarzi. “SMBHs have a radius comparable to that of our Solar System, and yet can only directly affect the motion of stars and gas in the very central regions of their host galaxies,” he says. It suggests they evolved together, he explains. “It has turned SMBHs from being exotic curiosities to an integral part of our understanding of galaxy formation.”





Hubble allowed scientists to create this 3D map of dark matter – the distance from Earth increases from left to right

DARK MATTER

This picture reveals the presence of something we can't see: 'dark matter'. The galaxies, stars and planets that we can see make up just 15 per cent of the Universe's matter. The rest – the other 85 per cent – is dark matter and it neither emits nor absorbs any known wavelength of light. "With this map, we saw for the first time where dark matter is," says Durham University physicist Dr Richard Massey. To construct it, half a million galaxies were observed by Hubble and ground-based telescopes. "When light travels across the Universe, it passes through all the intervening dark matter on its way to us, leaving a telltale imprint of its journey.

You can't see such faraway, faint galaxies from Earth because the atmosphere blurs the detail. This is why we needed Hubble," explains Massey. The dark matter bends the light in a 'gravitational lensing' effect, making the galaxies appear distorted. By observing this, it's possible to deduce where dark matter lies. Such a map is fundamental to understanding the Universe's structure, as dark matter acts as 'scaffolding', along which galaxies are assembled. "When the first explorers reached the American West, they sat on a ridge and tried to understand the lie of the land. We were doing the same thing on a new frontier," says Massey.

4

GENERATIONS OF STARS

Globular clusters are compact crowds of hundreds of thousands of stars bound together by gravity. For many years it was believed that all the stars within must be very similar, having formed close together from the same dusty cloud. But in 2005, Hubble measured the brightness and colours of stars inside the NGC 2808 globular cluster. Only one generation of stars was expected, but three were found.

Dr Giampaolo Piotto was the leader of the team that observed NGC 2808. "With an age up to 13.5 billion years – only 300 million years less than the age of the Universe – globular clusters are a benchmark for cosmology, and represent an ideal laboratory to understand

"You can't see such faraway, faint galaxies from Earth because the atmosphere blurs the detail"

star formation and chemical evolution in the Universe,” he explains. What defines the different generations of stars, also known as ‘stellar populations’, are characteristics such as their chemical composition, age, and their location in the cluster. Hubble’s high-resolution images allowed Dr Piotto and his team to look into the densely packed core of NGC 2808 and measure many stars – something that is difficult for ground-based telescopes to do. Hubble’s power to observe in both visible and ultraviolet light also made it easier to spot multiple populations of stars and track their evolutionary paths.

“We have now used Hubble to observe more than 60 globular clusters – almost half the known globular clusters in the Milky Way. Preliminary results show that all have multiple stellar populations,” says Dr Piotto.

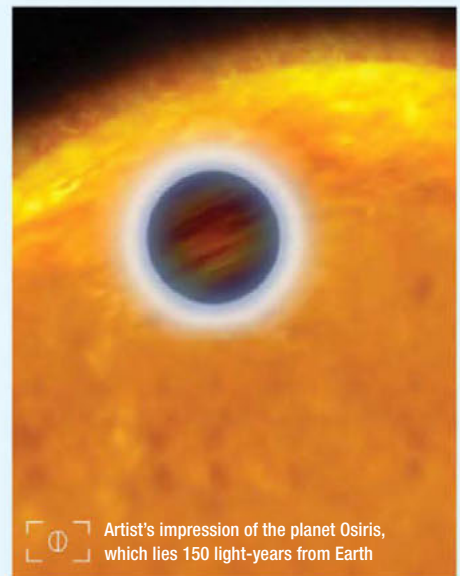


The NGC 2808 globular cluster contains over one million stars of three different generations

EXOPLANET ATMOSPHERES

As of February 2015, 1,890 planets had been detected orbiting stars other than our Sun. An impressive photo of one of these ‘exoplanets’ has yet to be taken, but Hubble was first to detect the atmosphere of one of these alien worlds.

HD 209458-b, also known as Osiris, is a planet 150 light-years from Earth. Temperatures reach a scorching 1,100°C as it orbits just 6.4 million kilometres from its parent star. As the orbiting planet moves in front of the star, some of the light passes through the planet’s atmosphere. This is analysed by a spectrograph, which is an instrument that splits the light into constituent wavelengths, explains Prof David Charbonneau, leader of the team behind the discovery. “The idea was to gather spectra when the planet was in front of the star and when it moved away. By comparing them, we would search for the appearance of new features when the planet was in transit. This required an extremely stable platform that was free from the absorption effects of our atmosphere. Only Hubble could do it!” In 2001, the procedure revealed signs of sodium – the first




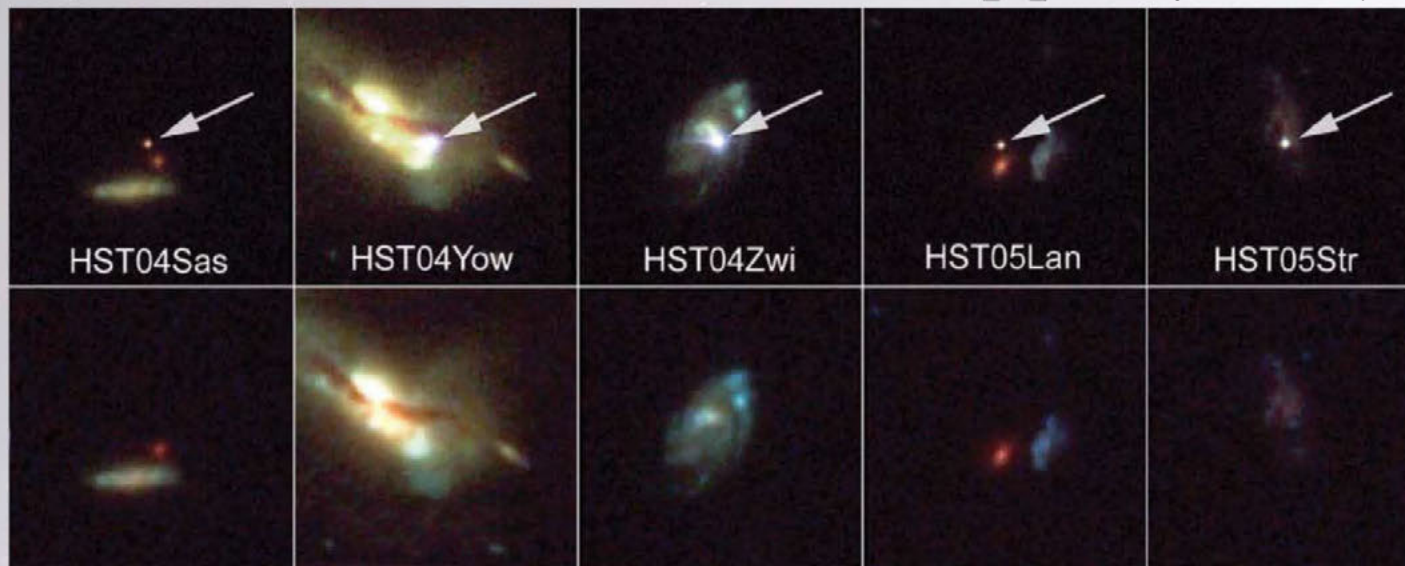
Artist's impression of the planet Osiris, which lies 150 light-years from Earth

atmospheric element detected on a planet outside of our Solar System.

“This same method has become the standard means to examine exoplanet atmospheres, and Hubble has now gathered similar data on dozens of worlds,” says Charbonneau.



 The arrows point to the supernovae; the bottom row shows the galaxies after the stars exploded



ACCELERATING EXPANSION OF THE UNIVERSE

These galaxies, hosting energetic supernovae (exploding stars), contributed to one of the most talked-about discoveries in recent years. Not only is the expansion of the Universe accelerating, it is being fuelled

by a phenomenon dubbed 'dark energy'.

In 1998, astronomers released new data on how the brightness of supernovae changed over time. It showed that the light coming from the most distant exploding

stars was fainter and more stretched (red-shifted) than predicted. It meant that they were further away than astronomers calculated – a result that didn't fit with the existing idea that the tug of gravity was causing the expansion of the Universe to slow down. For the team leading the project, this could only mean one thing: the expansion rate is not slowing at all. It's speeding up.

Hubble played a supporting role in this initial discovery by providing data for three of the supernovae that the team wanted to observe, with the rest coming from ground-based telescopes in Chile, Europe and the USA. "This result was so extraordinary that it required extraordinary evidence," explains Dr Adam Riess, one of the three Nobel prize-winning team members for the

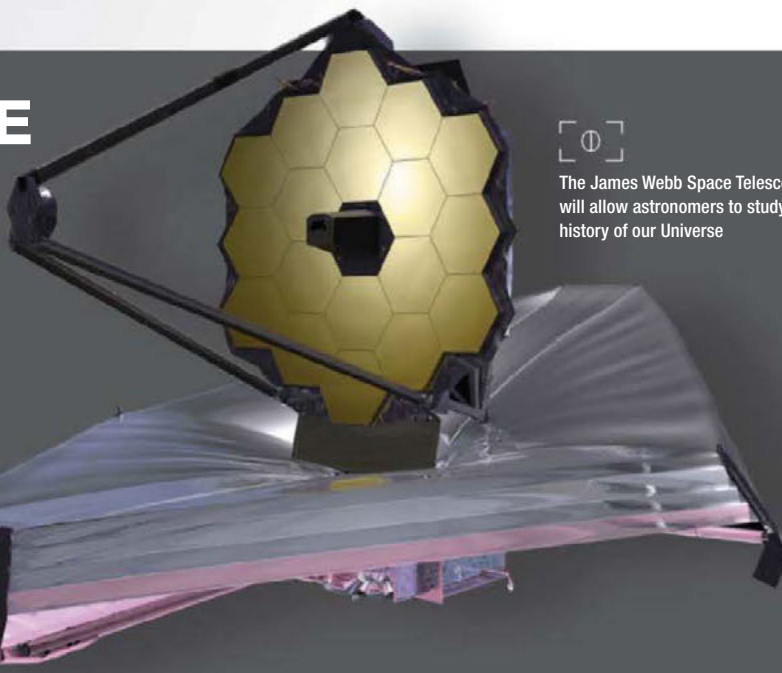
discovery. "This confirming evidence came from the Hubble Space Telescope."

By finding and precisely measuring another 16 supernovae at distances up to 10 billion light-years away, Hubble was able to confirm not just the acceleration, but that the Universe had indeed been decelerating in earlier times, just as predicted.

But to overcome gravity, something must be giving an opposing, repulsive force as the Universe expands and matter is spread out. This 'something' is dark energy, which makes up approximately 75 per cent of the entire known Universe. Hubble observations showed that this caused the acceleration we see today to begin about five billion years ago.

BEYOND HUBBLE

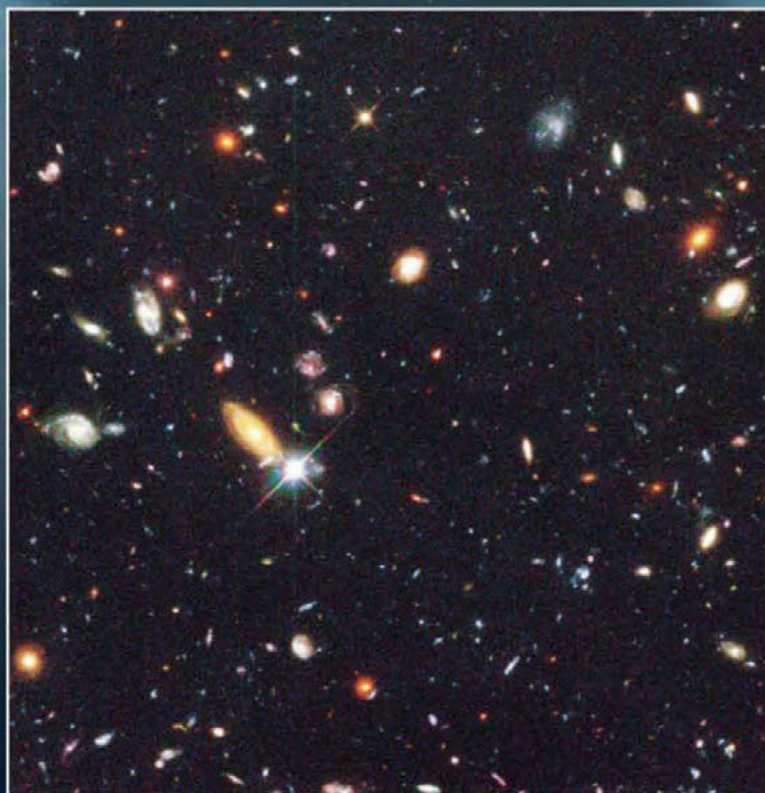
Hubble underwent its last servicing mission in 2009 and is expected to remain operational until it degrades around 2020. Hubble will then be sent into a final orbit back down into Earth's atmosphere to end its years of service in a blaze of glory. The highly anticipated James Webb Space Telescope (JWST) is due for launch in 2018, but it will not be a direct replacement for Hubble. Despite having a mirror almost three times as large, JWST will observe at a similar resolution but in a different wavelength of light – the infrared. It will be able to observe cold and dusty objects in amazing detail that previously appeared 'invisible', allowing astronomers to see further out into space, and back in time, than ever before.



The James Webb Space Telescope will allow astronomers to study the history of our Universe



Zooming in on a tiny patch of sky – the Hubble Deep Field. An incredible 3,000 galaxies of different sizes can be seen



HOW GALAXIES EVOLVE

This awe-inspiring image, dappled with beautiful shapes and a whole array of colours, changed the way we think about the distant Universe forever. One of Hubble's most famous images, the Hubble Deep Field (HDF) is a snapshot of a tiny patch of sky in the constellation Ursa Major. It covers an area of just one 24-millionth of the whole sky. And yet this minute window reveals around 3,000 galaxies crowded together, giving astronomers a vital window into the past.

There had been predictions that the light emitted from such distant objects would be stretched out so much that they would appear as nothing more than faint smudges against the blackness. They could not have been more wrong. This image, made up of 342 separate exposures taken over more than 100 hours, showcased the power of Hubble. It revealed an incredible amount of detail and structure to galaxies that had never been seen before.

"A lot of astronomers were sceptical that we would learn a lot from simply pointing the telescope at a fairly arbitrary spot in the sky and taking long exposures," says Dr Henry Ferguson, a member of the original HDF team. However, the plethora of information that appeared convinced most that this was a good technique. As the telescope's capabilities were upgraded, projects such as the Hubble Ultra Deep Field continued where HDF left off.

Today, astronomers are finding galaxies from a time when the Universe was only 500 million years old. As a result, it has become possible to chart galaxy evolution directly, by measuring how properties such as size, shape and colour change over time. "The HDF became one of the major 'watering holes' for studying galaxy evolution, with deep observations spanning X-ray to radio wavelengths," continues Dr Ferguson. "It is one of the most important observations ever made with any telescope!"

DEADLY ERUPT ME



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G A T I O N

April 2015 marks 200 years since Tambora exploded, searing into history as the most powerful volcanic eruption since records began. **Bill McGuire** asks if it could happen again...

The temperature is stifling, sucking the sweat from your body. Everything is utterly black. It is impossible to see your hand in front of your face. Worst of all is the blizzard of ash, falling so quickly that it clogs every orifice. You try desperately to suck in the scorching air, but the slimy concoction of ash and saliva that fouls your mouth and throat acts as a barrier. You are suffocating. It gets even hotter. A wave of blistering heat assaults your body, crisping your skin and bringing unimaginable agony. Your last act is to open your mouth to scream, but no sound emerges. Instead, you inhale super-heated gas that shreds your windpipe and destroys your lungs.

Death by volcano is not pleasant, as 12,000 inhabitants of the Indonesian island of Sumbawa discovered exactly 200 years ago. In April 1815, the island's Tambora volcano tore itself apart in the largest known eruption of the historical period, and one of the biggest since the Ice Age. But what happened in the weeks and months following the eruption, and will we ever be threatened by such an event in the future?

In many ways, those that succumbed to the deluge of ash and the tempests of boiling gases were the lucky ones. During the months that followed, five times as many people lost their lives on Sumbawa and neighbouring islands to the combined onslaught of famine and disease. And

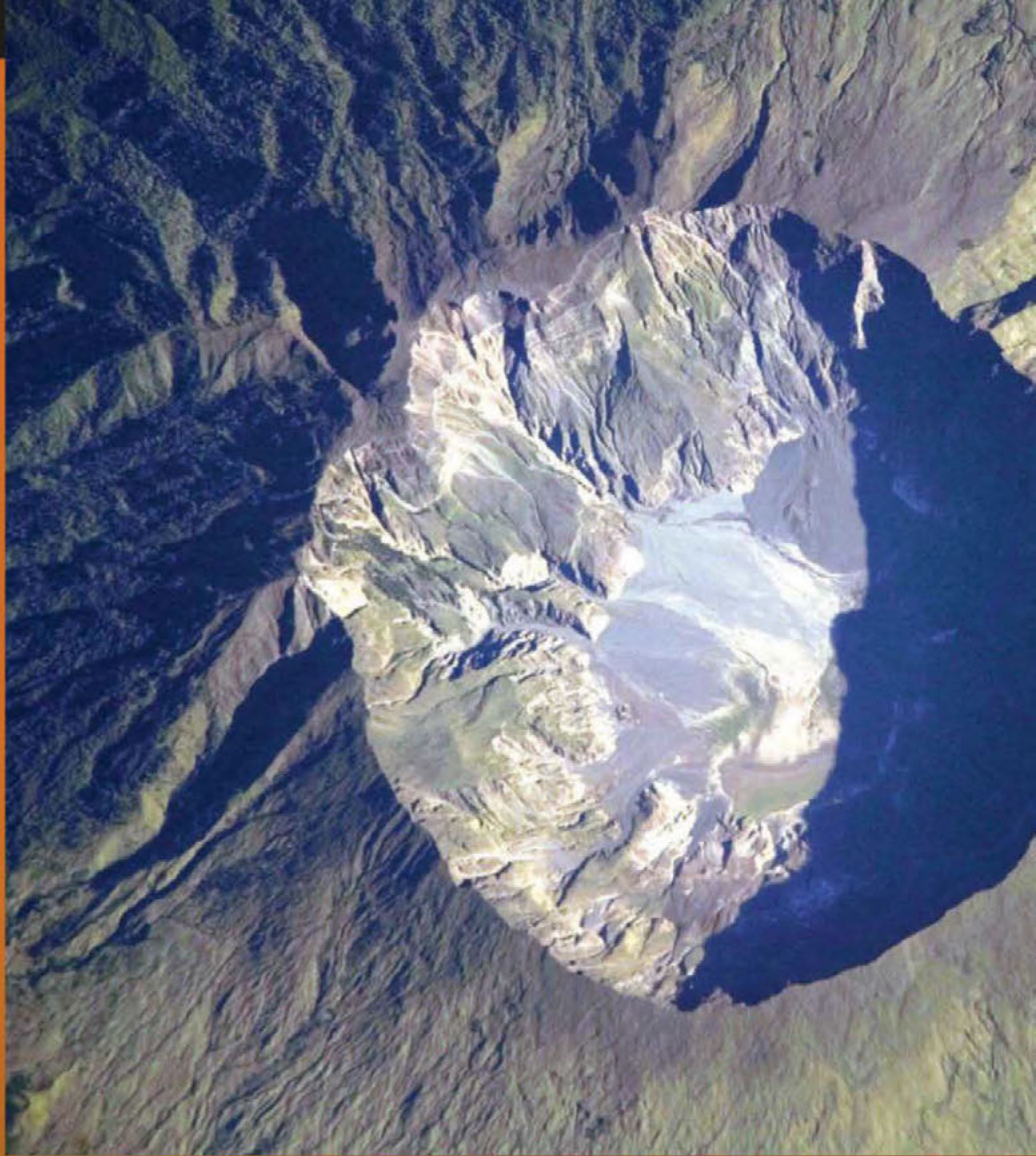


→ the lethal consequences did not end there; the huge volume of sulphur gases injected into the stratosphere caused climate mayhem half a world away.

As Tambora is secreted away on an obscure island in the Indonesian archipelago, the eruption might have gone unnoticed in Europe had it not been for a combination of fortuitous political circumstances. Having ousted the incumbent Dutch forces from the island of Java in 1811, a certain Thomas Stamford (later Sir Stamford) Bingley Raffles was installed by the British as Lieutenant Governor of the island. Famed today for establishing the city-state of Singapore and for the iconic hotel there that bears his name, Raffles also has the gratitude of today's volcanologists for the contemporary written accounts he provided of the Tambora blast.

As one of 78 active volcanoes in the world's most volcanically lively region, Tambora must have been a pretty impressive peak, with an estimated height of up to 4,300m. It had erupted just once in the previous five millennia, which undoubtedly convinced the local inhabitants that the volcano was long-extinct and presented no threat. It is possible that they did not even know the mountain was a volcano.

The first evidence that this optimistic assessment was way off the mark came in the spring of 1812, when the first rumblings began to make the local population nervous.



Left: Tambora's caldera is about 6km in diameter and up to 700m deep

TIMELINE

How it happened

1812

The first rumblings of the Tambora volcano for more than 1,000 years are followed by small detonations of steam and ash. Locals start to worry.

5 April 1815

The first major explosion lasts for two hours and sends ash to a height of 33km. The loud booms are misinterpreted in Java as cannon fire.

10 April 1815

A second blast launches the climactic phase of the eruption, which removes the top 500m or so of the volcano. Pyroclastic flows annihilate communities.

July 1815

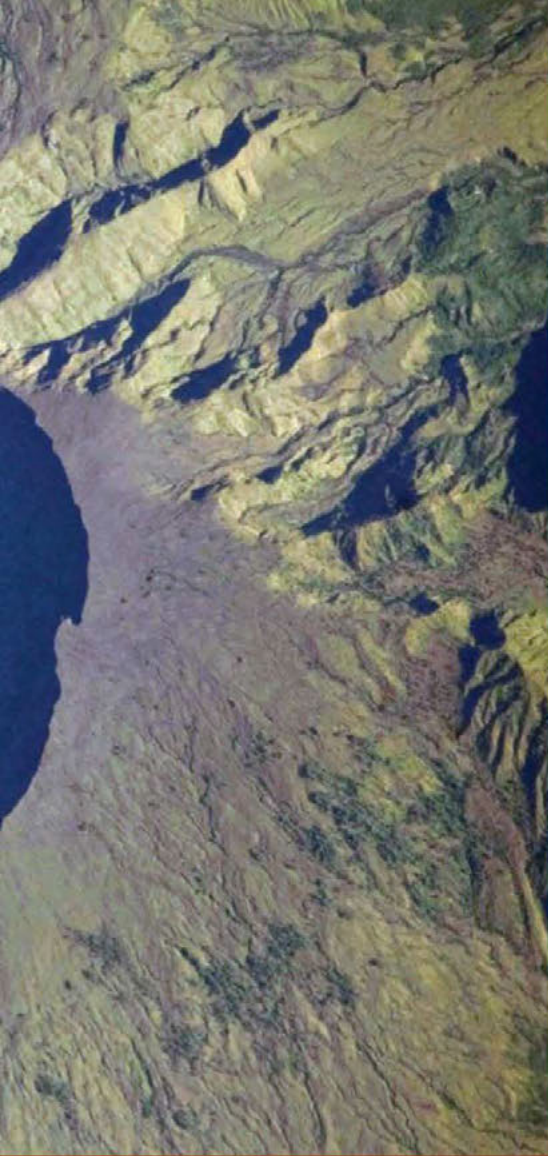
The explosions end, leaving behind a 6km-wide caldera. About 12,000 are dead and a blasted landscape is buried beneath huge amounts of ash.

Months after

The destruction of crops and the burial of agricultural land brings famine that takes an estimated 60,000 lives on Sumbawa and neighbouring islands.

Summer 1816

Unseasonably bitter weather wrecks harvests across the eastern United States and Europe. This brings bread riots, famine and disease.



LEFT: Tambora measures about 60km in diameter at sea level, forming the Sanggar peninsula

BELOW: Depth of ash that fell on Sumbawa and neighbouring islands when Tambora erupted



Skeletal human remains excavated from a buried Sumbawa village

“Starvation and disease were rampant, eventually taking the lives of an estimated 60,000”

Minor steam and ash explosions followed, but it was three years until things really started to get serious. The first titanic explosion occurred on 5 April 1815, the sound of which Raffles reports as carrying across to Java, where it spawned rumours of fighting and invasion. Following a short respite, a second colossal explosion five days later heralded the start of the climactic phase of the eruption, which seems to have lasted for three or four days. A gigantic,

45km-high column of ash reached to the edge of space, while hurricane blasts of scalding gas and hot ash scoured the surrounding land of all life. A powerful tsunami, spawned by the huge volumes of ash and debris flowing into the sea, buffeted the neighbouring coasts. When the ash-laden skies cleared weeks later, it was to reveal a decapitated volcano; its towering peak replaced by a hole measuring 6km across. The next few months were a living hell for survivors, whose homes and crops were buried beneath thick layers of ash. Disease and starvation were rampant, eventually taking the lives of an estimated 60,000 men, women and children.

Blast furnace

In total, the eruption blasted out a staggering 50 cubic kilometres of ash and debris – around five times that ejected by the more famous Krakatoa eruption, nearly seven decades later. More than 20cm of ash fell in eastern Java, while even in Borneo, 500km to the north, ash was 5cm deep. →



A coil of rope lies within the remains of a collapsed building on the island of Sumbawa

➔ Enormous rafts of pumice, some an astonishing 5km long, clogged the surrounding ocean, hindering shipping in the region for three years after the eruption. The detonations during the climactic phase were felt over an even wider area, shaking buildings across Java and heard as far away as Trumon in north Sumatra, 2,600km from the volcano.

While the statistics of the Tambora eruption are impressive, the event is best known for its wide-ranging impact on the climate. The enormous volumes of ash settled out of the atmosphere in a matter of weeks. The 200 million tonnes of tiny sulphate particles, injected into the stratosphere, however, hung around for much longer, forming a so-called aerosol veil across the planet.

The big chill

This veil proved very effective at blocking incoming sunlight, causing temperatures to plunge and inflicting an unseasonable chill upon the northern hemisphere. Earmarked in the historical record as 'the year without a summer', 1816 saw snow in New York state in June and unprecedented summer frosts wiping out crops across the eastern states. In Europe, the summer was the second coldest of the past six centuries, bringing widespread crop failures. The bread riots, starvation and disease that followed have been described as marking the last great subsistence crisis in the western world, taking – in Ireland alone – as many as 44,000 lives. Tambora's remote



Above: Eyjafjallajökull in Iceland caused chaos to European flights when it erupted in 2010



Left: JMW Turner's paintings, such as *Chichester Canal*, celebrate the orange-tinged sunsets that were seen following Tambora's eruption

legacy also had some surprising cultural consequences that remain with us today. The brilliant, sulphurous sunsets that followed the eruption have been held up by some as providing inspiration for the increasingly flamboyant skies of some of JMW Turner's post-1814 works. Similarly, the weather of 1816 is charged with

supplying the brooding backdrop that – during a 'wet and ungenial' summer spent at the Villa Diodati on Lake Geneva – inspired Mary Shelley to write *Frankenstein* and prompted Lord Byron to compose his poem, *Darkness*.

Now, 200 years on, we await the next Tambora with some trepidation. Volcanic

THE NEXT TAMBORA?

Volcanologists can pinpoint when an eruption will take place, but many volcanoes remain unmonitored

When provided with a half-decent geophysical monitoring network, volcanologists are pretty good at predicting when an eruption might occur a week or two before it takes place. Pinpointing in advance the next Tambora is a different kettle of fish, especially given that there are at least 1,300 active volcanoes around the world, only a fraction of which are currently monitored. We can, however, try and narrow the odds a little. Bearing in mind that half of the 20 biggest eruptions

since 1800 occurred at volcanoes that – like Tambora – had not erupted in historic records, we should perhaps focus on those seemingly innocuous volcanoes that have been quiet for millennia, especially those that are showing signs of life. Restless Mount Paektu on the border between North Korea and China immediately springs to mind, along with steadily swelling Uturuncu in southwestern Bolivia and the rapidly inflating Laguna del Maule volcano in Chile.

Could Mount Paektu be the next volcano to erupt?



An infrared view of Tambora, taken from space

“The weather of 1816 supplied the brooding backdrop that inspired Mary Shelley to write *Frankenstein*”

blasts on this scale seem to happen, on average, a few times every millennium. The probability of another one coming along in the next 50 years is maybe 10 per cent, or even higher. Based on the three-year escalation of activity that preceded Tambora’s climactic explosion, it may be that we will have a decent lead-in time

before the next great volcanic blast, giving us the opportunity to plan for the event. The problem is that we are still not able to determine if increasing restlessness at a candidate volcano will end in an Earth-shattering eruption or a return to slumber. With a number of potential future Tamboras already bubbling and swelling in

various regions, the stage may be set for the next ‘big one’.

So, given what we now know about massive eruptions and the potentially disastrous impact they can have on the climate, will we be ready? Sadly, it would come as no surprise if we were caught out. After all, we were completely unprepared for the relatively minor eruption of Iceland’s Eyjafjallajökull in 2010, which played havoc with air travel across Europe, even though it was only a little over half a century since Icelandic ash last invaded European airspace. Clearly, when it comes to the impact of volcanic eruptions, we have very short memories. Before it’s too late, let’s hope that we don’t forget the important lessons Tambora has taught us about the devastating and far-reaching consequences a single volcanic blast can have for our world. ■

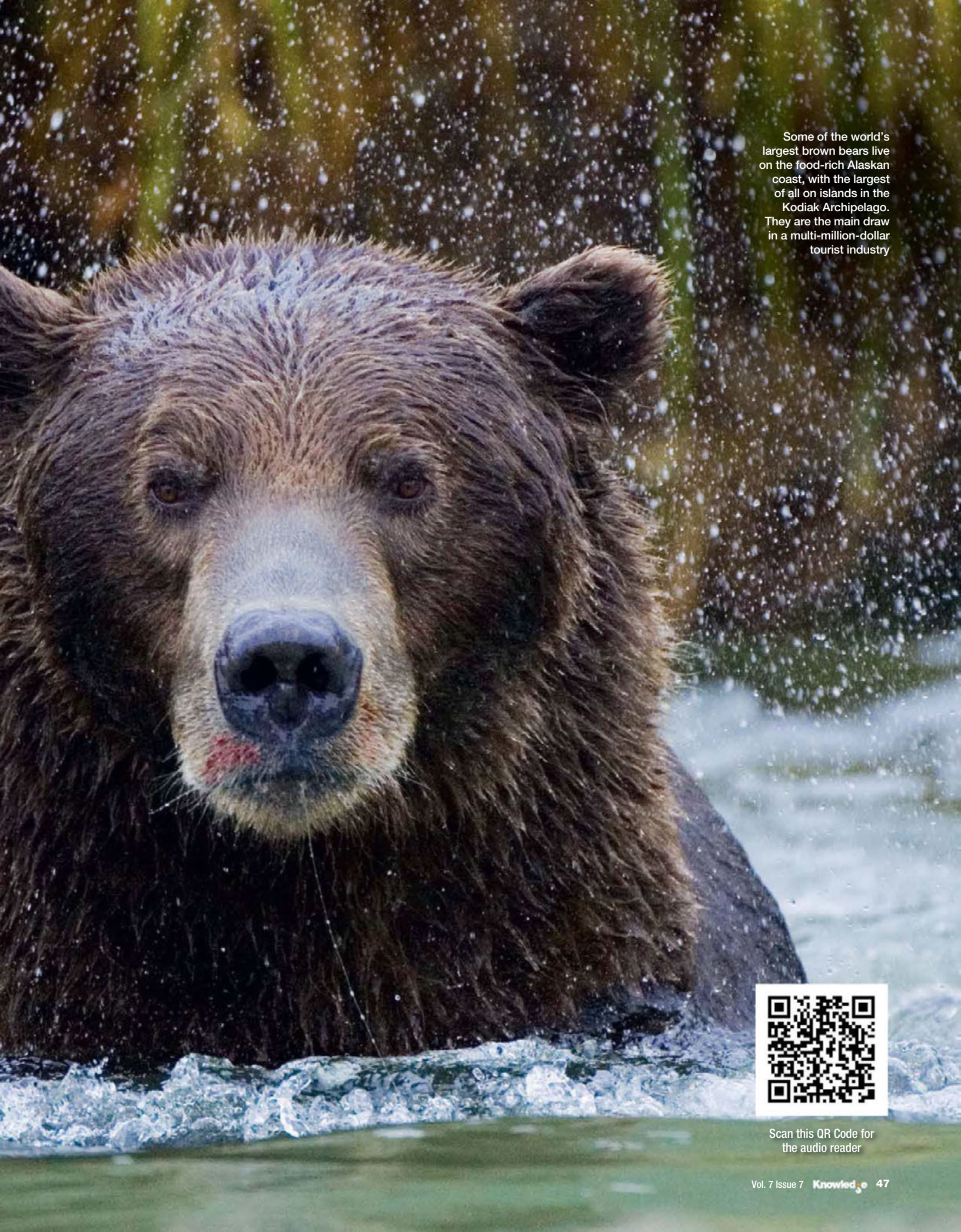
BILL MCGUIRE is Professor Emeritus of Geophysical and Climate Hazards at UCL. His current book is *Waking The Giant*

LOVING BEARS TO DEATH

Photos by Suzi Eszterhas

Brown bears have no shortage of fans worldwide, yet conflict with these animals is growing and hunting is on the increase.

Isabelle Groc asks if the great Alaskan wilderness is big enough for both bears and people



Some of the world's largest brown bears live on the food-rich Alaskan coast, with the largest of all on islands in the Kodiak Archipelago. They are the main draw in a multi-million-dollar tourist industry



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Above: As bear cubs grow, their mother (here in Katmai) teaches them how to forage and fish, how to interact with humans, and who the 'good' and 'bad' bears in the area are

Right: A young cub. Brown bears enter their 'teenage' years between the ages of three and five

Surrounded by wilderness, the 290,000 residents of Anchorage live in bear country as much as the bears live in human country. Sean Farley, who monitors these animals for the Alaska Department of Fish and Game (ADF&G), found that at least 35 individuals visit this urban area, heading into town to hunt moose calves in spring, and following city trails to salmon-spawning streams in local parks in summer.

"Brown bears blend into their habitat amazingly well," says Farley. "They move off a trail when somebody walks past with a pushchair, then will be back on the trail and continue on their way." Sometimes bears and people do run into each other, and recently the number of maulings has increased as the bear population grows and the boom in outdoor recreation continues. But most attacks occur when bikers or runners travel fast along a path and surprise a bear at close range.

Over the years ADF&G has culled only a handful of brown bears here – those which were repeatedly scavenging refuse and had become a public-safety issue. "We don't remove bears just for being bears," says Jessie Coltrane, the agency biologist responsible for the area.

Conflicts can be greatly reduced by encouraging residents to bear-proof their dustbins, install electric fences around chicken runs and use common sense. "Going for a jog

next to a salmon creek when the fish are running is high-risk," cautions Coltrane, though given the number of brown bears visiting the city, incidents are remarkably rare: "People tend to behave badly, not bears."

Wild neighbours

Despite the potential dangers, when Anchorage residents were asked in 2010 for their opinions on bear and moose populations, they were generally tolerant of both. Most people thought that having large mammals in the city made life more interesting (there are also 250–300 black bears and four wolf packs in the area).

Indeed public attitudes towards brown bears in North America have changed dramatically. "People are realising that you can live with bears if you understand them," says Larry Van Daele, who has spent the past 30 years working with the animals for the ADF&G.

However, this was not always the case. With more than 30,000 brown bears, Alaska has 98 per cent of the US population, but in the early 1800s an estimated 50,000 individuals roamed the pristine landscapes between the Great Plains and the Pacific Ocean. As European pioneers moved in, the bears were persecuted. Their numbers and habitat declined drastically to the point of local extinction.

In 1975 the brown bear was finally listed as a threatened species under the US Endangered



REARING CUBS: GOOD AND BAD MOTHERS

Brown bear cubs are born underground in January or February, and emerge in June. Two or three cubs is a typical litter, though four is not unusual in food-rich coastal areas. The family will stay and den together for the next two to three years, with the mother teaching her offspring everything she knows.

Researchers have noticed that while some bears are good mothers, others are never able to wean a litter successfully. "Bears have individual personalities – they're like people. Some are better parents than others," explains Sean Farley, who studies differential reproductive success among females. On the Kenai Peninsula, for example, he found that 80 per cent of the cubs that make it to weaning age are raised by 20 per cent of the females.



Species Act in the lower 48 states, where only 1,500–1,700 animals now persist in about 2 per cent of the former range. Of these, the two main populations are in the Northern Continental Divide ecosystem in north-west Montana and the Greater Yellowstone Area. The other surviving populations are very small and fragmented.

Bear celebrities

Today people all over the USA, Canada and further afield have a newfound appreciation for the bears, and a desire to see them too. Each summer thousands of tourists make the pilgrimage to Alaska to watch them catch salmon at hotspots such as Brooks Falls in Katmai National Park or the McNeil River State Game Sanctuary, both on the Alaska Peninsula. By 2011 wildlife watching was injecting US\$1.2 billion a year into the state economy.

But it's online that the American love affair with bears has really stepped up a gear. Live streaming from Brooks Camp in Katmai has transformed its residents into soap-opera stars, enabling viewers to make personal connections with bears without having to travel to remote forests, rivers and mountains. The extent of the national feeling for the animals was particularly apparent last July, when a seven-year-old female called Bear 130 or 'Tundra' was found dead, possibly killed by a rival. Tundra was well known, and fans worldwide mourned her death. "She was a bear with a story," says Troy

Top: A Kodiak bear ventures onto the streets of Larsen Bay from the surrounding wildlife refuge

Above right: Tourists flock to see Katmai's bears in summer

Above left: A mother and her three-to-four-month-old cub forage for clams on Katmai's shoreline

Hamon, the park's chief of natural resource management and research. "Connections like these can have a hugely positive impact, helping to develop a constituency for these animals and where they live."

Brad Josephs has led bear-viewing expeditions along the coast of Katmai for the past 14 years. "Bears are majestic and humbling, and I want to leave people with a much stronger sense of their value in the wild," he says. For Josephs, bear conservation goes beyond the animals themselves. "Brown bears symbolise wilderness," he adds.

But Josephs is disheartened by the fact that more love does not necessarily translate into a greater conservation effort. Over the years he has seen the nature and intensity of bear tourism change, particularly with day-trippers increasingly flying into the Katmai coast. "We have turned an area of critical bear habitat into an airport," he says. The animals are very sensitive to noise, and Hamon notes that they are shifting their routine. In Hallo Bay, for example, the number of bears present in the meadow can double after the last plane leaves.

Live streaming from brooks camp in Katmai has transformed its residents into soap-opera stars

Too close for comfort

Because bear viewing takes place where individuals gather



at concentrated food sources, its impacts can be significant. Since 2000 Anthony Crupi, a biologist with the ADF&G, has studied the interactions between people and bears on the Chilkoot River, a popular fishing and unregulated viewing site near the town of Haines. Easily accessible via the Alaska Highway, this narrow, 3km-long stretch of river attracts more than 80,000 visitors every summer.

Around 15–20 bears – adult females, cubs and sub-adults – congregate at the Chilkoot River to feast on migrating coho, pink, sockeye and chum salmon. Crupi's research has shown that when people are absent or at least 100m away, the bears spend more time at the river, capture two-and-a-half times as many fish, and catch greater proportions of live prey. Unfortunately, in the absence of regulation and management, visitors frequently approach the bears to within a few metres.

"It is sad for these animals," says Crupi. "They provide so much to the economy and enhance our sense of wilderness, but at the cost of their own success. Everybody wants to experience this place, but ultimately it is causing conservation concern for a keystone species."

For many years Crupi has been following the progress of Bear 443, a 26-year-old female considered to be the most dominant individual on the river. More tolerant of people than her peers, she caught more fish and was a highly successful breeder, raising 13 cubs in 16 years. But her strategy has come at a cost. Because their mother was willing



Above: Migrating salmon are a vital food source for brown bears. A dominant male can catch and eat up to 30 fish a day

Above right: Sub-adult bears such as this one are independent, but have yet to reach sexual maturity

to hunt in close proximity to humans, the cubs picked up bad habits. The youngsters learned that fish carcasses were easy to obtain from anglers, leading to inevitable conflict with people from the surrounding neighbourhoods and, eventually, death by shotgun. "Only one cub survived long enough to have babies of her own," says Crupi. Brown bears are generally slow to reproduce – only one in three typically reaches maturity. In the Chilkoot River area, the survival rate is even lower.

Hunters vs tourists

Then there is the vexed issue of hunting. North America's hunting lobby is undeniably powerful – according to a 2011 survey by the US Fish and Wildlife Service, 13.7 million people in the USA over 16 years old said they were hunters.



As in many other parts of Alaska, the same bears that are viewed by tourists on the Chilkoot River in summer are hunted for sport in autumn, a source of ongoing controversy.

Kodiak Island, which is home to about 3,500 bears belonging to the largest subspecies of brown bear in the world, has an active trophy hunt. “If you visit in July you will be watching bears; in November you will be shooting them,” says Van Daele. “Bears are a resource to be managed for the benefit of many groups of people. So who has priority – somebody who wants to watch a bear, or somebody who wants to harvest one?”

A paper published in 2011 in *The Journal of Wildlife Management* showed that regulations for hunting brown bears were liberalised and increasingly designed to reduce bear abundance between 1980 and 2010, resulting in longer hunting seasons and more kills. In 2007, for instance, roughly 1,900 Alaskan brown bears were harvested, the vast majority taken by sport hunters. In some regions the state also culls bears and wolves to protect moose and caribou populations.

There are only a handful of areas in Alaska where brown bears are not hunted, including Katmai National Park and McNeil River State Game Sanctuary. But the bears that ecotourists enjoy here are capable of travelling long distances, and are likely to be shot as trophies if they enter adjacent locations where hunting is allowed. This creates a moral dilemma: is it acceptable to hunt bears that trust humans?

Hunters and wildlife managers alike believe that bears are intelligent, adaptable animals that can distinguish between a camera-wielding tourist and a gun-toting hunter, particularly because they utilise different locations at different times of year. “In summer, bears at

KODIAK'S SAFE HAVEN

Alaska's native peoples often have a different attitude to hunting, and in 2014 the Alutiiq people of Kodiak Island decided to exclude hunters from 14km² of prime bear-viewing land around the northern portion of Karluk Lake. This is the first and only area closed to bear hunting on Kodiak Island. “We felt it was needed because these bears have become acclimatised to our presence. Hunting them was not a fair deal,” says Edward Ward of the Kodiak Brown Bear Center, the native-owned organisation that runs bear-viewing tours. “Closing that land is a testament to our native culture, which respects the bears and gives them space.”

salmon streams are highly tolerant of people and each other,” says Van Daele. “But if the same bear sees a person or another bear in autumn, they don't want to be there.” Ultimately, however, it's hard to prove whether individual bears can differentiate between dangerous and harmless humans.

Hunters argue that they have less impact on bears than wildlife watchers – and do more for conservation. Sam Rohrer, president of the Alaska Professional Hunters Association, guides both bear hunters and viewers on Kodiak Island. “When I am hunting, I observe from afar. I only interact with the one bear I kill,” he says. “When we are bear viewing, we're up close and personal and can be interacting with as many as 20 individuals.”

The danger of complacency

The justification for exploiting brown bears in multiple ways has long relied on the fact that Alaska has healthy bear numbers. But higher harvest rates, the state's growing human population, oil and gas extraction, and the impacts of climate change are piling on the pressure. For example, noise and vibration from drilling in the North Slope region of the Brooks Range can disturb denning individuals.

“If you are visiting in July you will be watching bears; in November you will be shooting them”



“Alaska is big and remote, so will probably always have brown bears. but you can cause local extinctions”

SNIFFING THE SNOW

In the coastal region of the North Slope, oil and gas exploration occurs in winter, when brown bears are in dens. Regulations require industry activities to keep 800m away from the dens, because disturbance may cause a female to emerge prematurely and affect cub survival. But locating a denning bear under several metres of packed snow is far from easy, even with infra-red technology. A few years ago biologist Richard Shideler brought his two Karelian bear dogs to the oil fields. They sniffed out 92 per cent of denning bears – a much better result than any other method of detection.

Above: Bears can severely injure each other in a fight, so try to avoid conflict. Skirmishes are most likely to occur when in competition for food. These males are in Katmai NP



Dogs can locate bear dens hidden under the snow

KARELIAN BEAR DOGS: ADRIANO BACCHELLA/NATUREPL.COM

Chris Morgan, one of America's leading brown bear ecologists, sounds a note of concern. “Alaska has a lot of bears. But as a result there is a false sense of security when it comes to managing them,” he says. Complacency can be the enemy of conservation.

The vulnerability of Alaska's brown bears became apparent on the Kenai Peninsula after the Alaska Board of Game approved more liberal hunting regulations there in 2012. A record 184 animals were killed in 2012–14, including 42 valuable adult females of breeding age. In 2014 the high level of mortality – six-and-a-half times the annual average over the past 50 years – prompted a change of heart, and the federal government enacted a temporary sport-hunting ban at Kenai National Wildlife Refuge.

“Current levels of mortality are causing a substantial decline in Kenai's bears, and that is not consistent with our mandate of managing wildlife populations in their natural diversity,” says Andy Loranger, manager of the refuge. Part of the problem is that the Kenai bear population is isolated and genetically less diverse than the brown bear population on the mainland. As Sean Farley says, “Alaska is big and remote, so will probably always have brown bears. But you can cause local extinctions if you're not careful.”

Brown bears have been persecuted for centuries, yet Morgan remains optimistic. “More and more people are realising that bears represent something we need,” he says. “They stand for vast landscapes full of fresh water and clean air. They are good for all of us.”

ISABELLE GROG is an environmental writer and wildlife photographer based in British Columbia (www.tidelifa.ca).

MEET THE FIRST DIGITAL LIFE FORM

This worm is just a collection of bits and bytes, but in the virtual world it wriggles like the real thing. **Katherine Nightingale** asks whether it's really alive...



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There is a tiny worm, measuring just one millimetre in length, which is a scientific giant. It survived crashing back to Earth in the Columbia shuttle disaster of 2003, it was the very first organism to have its entire genome sequenced, and it is the only species for which we have a complete wiring diagram of its nervous system.

The worm in question is a nematode. Also known as *Caenorhabditis elegans*,





this tiny soil-dwelling roundworm has been pulling its weight in the laboratory for decades. And it could soon be adding another first to its list – it's well on the way to becoming the very first animal to be digitally recreated in a computer.

But why do we want or need digital worms? What can we learn from a worm that is made out of bits and bytes, and will these digital creatures be truly 'alive'?

C. elegans is a lab favourite because it is simple, consisting of just 959 cells. Of these, 302 are neurones (nerve cells). It is easy to keep and breed in petri dishes of agar. We know more about the little *C. elegans* nematode than any other lab animal, and it shares a surprising amount of its genetic code with human beings.

This makes it an ideal candidate for studying human genetics and disease, and it is a good place to start if you want to create a digital animal from scratch.

The virtual worm can be experimented on much more easily than a real worm, says Stephen Larson, one of the founding members of the OpenWorm project behind the initiative. According to Larson, who has a background in neuroscience and computer science, any worms produced will be 'editable', rather than finished products. There might even be scope to carry out experiments that aren't physically possible in the lab.

"The goal is that it's not just interesting, but it's helpful – you can ask hypothetical questions in the digital worm and then go and check in the real worm," he says.

Build a beastie

But it could also be a useful test of whether such a feat would be possible for other animals, or even humans. For example, a simulated human brain inside a computer would be helpful for studying various

"YOU CAN ASK HYPOTHETICAL QUESTIONS IN THE DIGITAL WORM AND THEN GO AND CHECK IN THE REAL WORM"

Stephen Larson, founding member and coordinator of the OpenWorm project



Stephen Larson wants to know how computers can help us to understand life



These roundworms were flown to the International Space Station to study muscle loss in a low-gravity environment

Scanning electron micrograph of the *Caenorhabditis elegans* roundworm. From tip to tail it measures just 1mm



diseases. This is the aim of the field of artificial intelligence – the development of computer systems that can carry out tasks of which only human beings are normally capable. There are two ways that you could go about building a digital *C. elegans*. The first is to program a worm-like creature so that it moves like a worm and responds to certain stimuli the way a worm does. This is the way that artificial intelligence efforts usually work, aiming to reproduce human-like intelligence without also reproducing the brain's physiology.

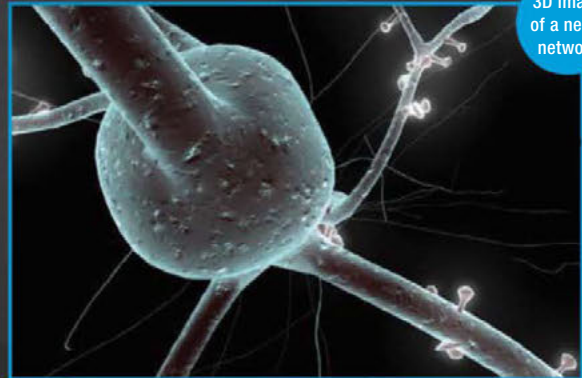


ARTIFICIAL LIFE

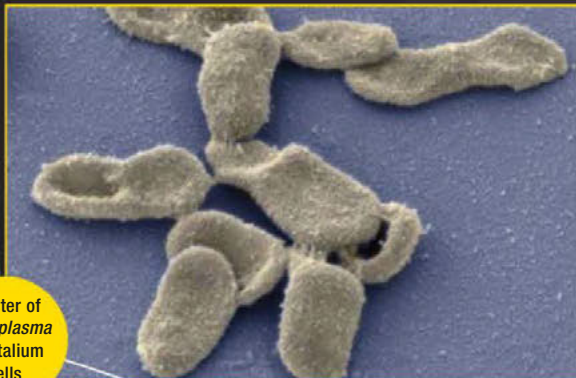
It's not just the nematode that's getting computerised – the digital tree of life has many different branches

THE HUMAN BRAIN PROJECT

This 10-year project aims to simulate a human brain in a supercomputer. Backed with €1bn from the European Union, it involves 112 organisations in 24 countries in Europe and the rest of the world. But it has been criticised by some scientists for being premature and misdirected.



3D image of a neural network



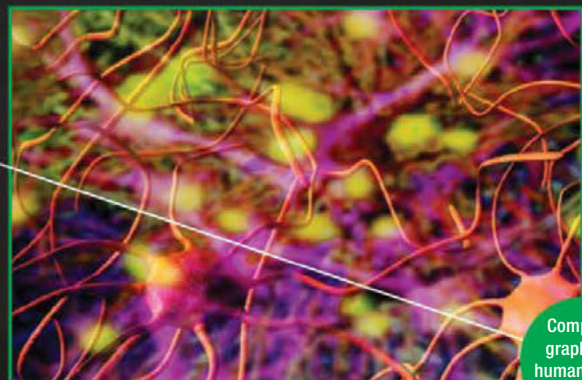
Cluster of *Mycoplasma genitalium* cells

A DETAILED CELL

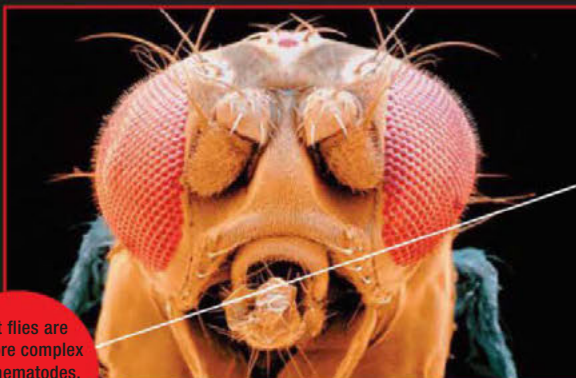
The laboratory of Professor Markus Covert at Stanford University in the US built the first digital model of an entire organism. The organism is a single-celled parasitic bacterium called *Mycoplasma genitalium*, but its tiny size didn't make it any easier to simulate – the researchers attempted to include all the cell's processes integrated together.

THE BRAIN INITIATIVE

The BRAIN (Brain Research through Advancing Innovative Neurotechnologies) Initiative was announced by the US Obama Administration in 2013. It aims to map the activity of every neurone (nerve cell) in the human brain. Inspired by the Human Genome Project, it is likely to cost billions of dollars over 10 years. It has also received criticism from researchers.



Computer graphic of human nerve cells



Fruit flies are far more complex than nematodes, with thousands of neurones

A FRUIT FLY'S BRAIN

NeuroKernel is a project aiming to reproduce the brain of the fruit fly (*Drosophila melanogaster*) in a computer. The fruit fly brain has up to 150,000 neurones, and is a common model for studying genetics. Like OpenWorm, NeuroKernel is open source.

➔ But just recreating behaviour isn't the goal – that wouldn't be particularly useful for finding out how the real worm actually works. OpenWorm is building a cell-for-cell replica of the worm, so we can start to understand how its behaviour emerges out of its physiology. So what do you need to build a worm in a computer?

Well-connected

The *C. elegans* connectome has been around since the 1980s. This is a map of how all its neurones are wired up, although it has been improved upon since it was first assembled. The team has also used a three-dimensional body plan of the worm, which includes its muscles, nervous system and skin.

But just having a map isn't good enough – you need to know how the cells are behaving too. For this, the team has turned to the reams of scientific data on the functions of *C. elegans* cells and how they interact.

Larson and his colleagues – who are all volunteers – are spread throughout the world and keep costs low by meeting virtually

online. The OpenWorm project, which began in 2011, is an example of 'open science' – they publish all their code on the internet for anyone to use, and conduct all of their meetings and discussions in public forums.

In this respect, it's a thoroughly modern project. It began with a tweet in 2011, and although OpenWorm receives no science funding in the traditional sense, it raised more than US\$120,000 on Kickstarter in 2014.

Larson can see many advantages to this way of working. "Everyone is really excited and passionate – if they weren't, they wouldn't be working on it," he states.

And it's lucky that they are excited, because a lot of work is required to simulate a worm in a computer. All of the models are simply an approximation of the thing they are trying to replicate. The question is how closely a model has to resemble the original, and how much detail you go into. It's a case of making trade-offs, says Larson. Science knows a lot about *C. elegans*, but it doesn't know everything you'd need to make a comprehensive model.

"It's going to be

quite a while before 100 per cent of that data is available, so we know that we have to take advantage of some really good, intelligent guesses about certain aspects of the model. We've chosen this animal because we'll have to make the fewest guesses with it than with anything else," Larson says.

The team members aren't drilling down to the level of what's going on inside cells. That would require vast amounts of computing power, and it probably isn't necessarily going to get the digital worm behaving like a real one. Instead, they're starting with locomotion.

This colourful 3D rendering shows the connectome of the *Caenorhabditis elegans* roundworm, with its 302 neurones

WRIGGLE LIKE A WORM

This rendering shows how the digital worm will move. The contraction of its muscles is driven by nerve signalling, enabling it to crawl in a smooth motion



**"WE'VE CHOSEN
THIS ANIMAL
BECAUSE WE'LL
HAVE TO MAKE
THE FEWEST
GUESSES"**

Stephen Larson, founding member
and coordinator
of the OpenWorm project



Stephen Larson (above) says, "Our interest in smarter AI is to learn principles of modelling neurones that will give us insight into human intelligence"

So far, they've got a complete model of the nervous system, and have created a model of the worm's 95 muscles. They've also produced a virtual worm body that crawls in a digital simulated environment.

"We're working to plug the nervous system into this, so that the motor neurones are influencing the muscles. And we have the integration environment that can display the results of a worm simulation on the web," says Larson. The integration environment is called Geppetto, and the goal is for people to use it to play with the worm simulation via their web browser.

Starting with the nervous system and muscles means that easily visible behaviour is simulated, which can then be compared with how real *C. elegans* worms move in the lab. This lets the team see how close the model is to the real thing.

One day, the team hopes to include

processes like digestion and reproduction. But for now, it's all about how the worm moves through its digital agar.

So if we can do it for a worm, can we do it for other animals as well? Murray Shanahan, Professor of Cognitive Robotics at Imperial College London, thinks it's possible. The main obstacle will be getting enough data about, say, the 75 million neurones in a mouse brain to have enough information to build a model. We don't have a mouse connectome yet, and we don't understand the behaviour of many of the neurones.

But, explains Shanahan, there has been a huge amount of progress in studying brain activity in mice at that neurone-level scale in recent years. "I'd be surprised if we couldn't [simulate a mouse brain] in 20 years and I wouldn't be surprised if we could do it in 10," he says.

Laws of life

So, if it looks like a worm, crawls like a worm and responds like a worm, then is it a worm? Even if the project manages to simulate all the components of the worm, and it is reproducing, feeding and moving around in a digital version of its agar, it is still not alive, says Alan Winfield, Professor of Electronic Engineering at the University of the West of England and a Bristol Robotics Laboratory researcher.

"There are plenty of video games in which the virtual creatures also arguably have those characteristics and we never think of those as alive. They are simulations – a simulation of a thing is not a thing," explains Winfield.



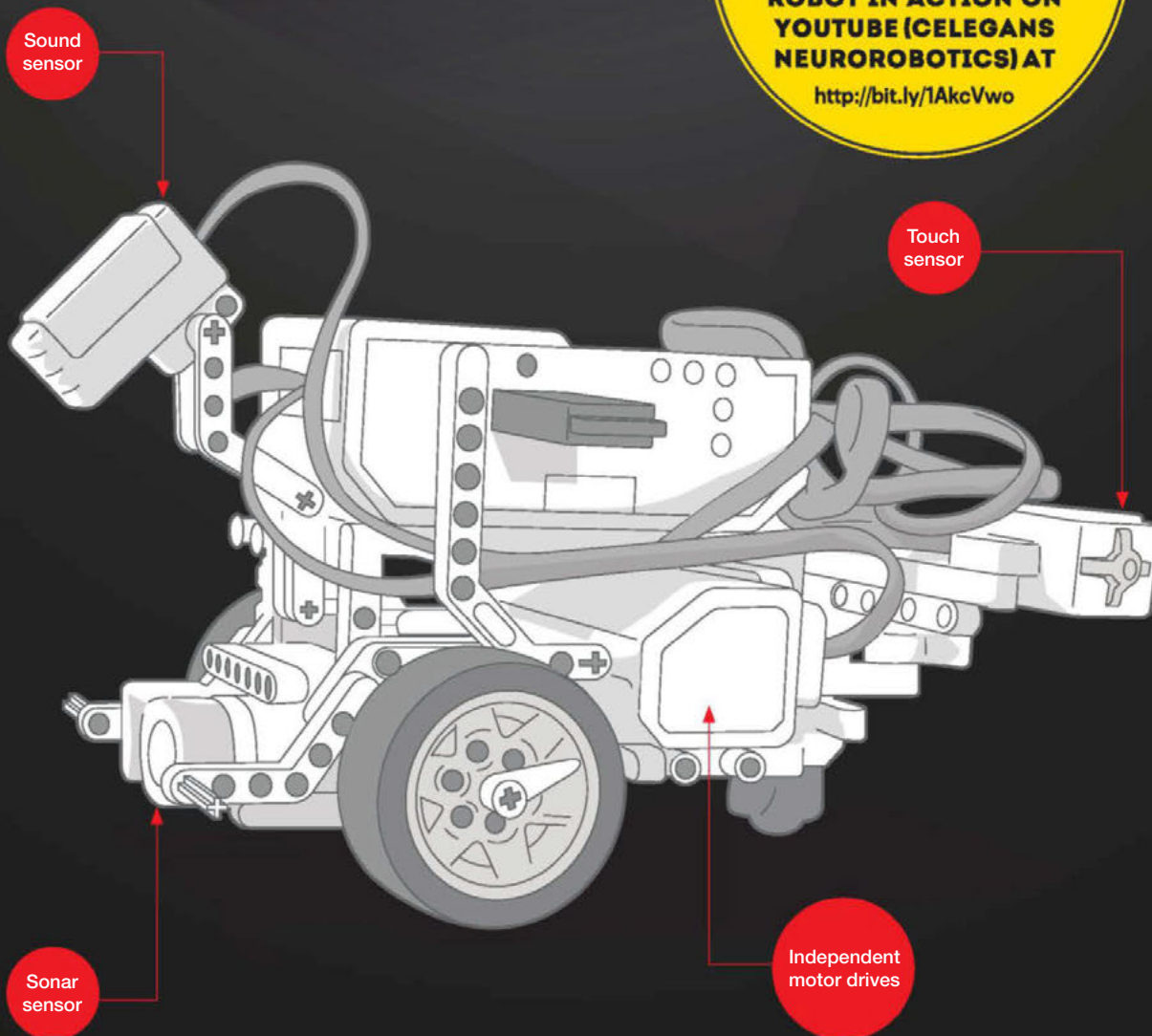
LEGO WORM

What happens when you combine a worm's connectome with a children's toy? You get a pretty cool robot...



**WATCH THE WORM
ROBOT IN ACTION ON
YOUTUBE (CELEGANS
NEUROROBOTICS) AT**

<http://bit.ly/1AkcVwo>



In 2014, researcher Timothy Busbice put a neural network into a Lego robot, which was based on the *Caenorhabditis elegans* worm's connectome. The robot's two wheels are controlled by 95 cells to replicate the muscles of the

roundworm. The worm's sensory organs, which would normally respond to smells and tastes, are instead wired up to respond to sound, while its touch-sensitive 'nose' has been replaced with sonar. In one online video, the robot is seen

approaching a wall and then backing away. Rather than this being a behaviour that has been programmed into the robot, it's thought to be an outcome of the worm's neural network.

OpenWorm founder Stephen Larson has yet

to 'look under the hood' of the Lego robot with his team, but he says: "We are excited about people being creative and we'd love to see a lot more people plugging ever-evolving versions of the model nervous system into robots."

"PEOPLE MIGHT HAVE A STRONGER REACTION TO SOMETHING THAT'S IN A PHYSICAL BODY"

Alan Winfield, University of the West of England

Pictured is a top-down view of the connections between neurones (nerve cells) in the brain of a mouse

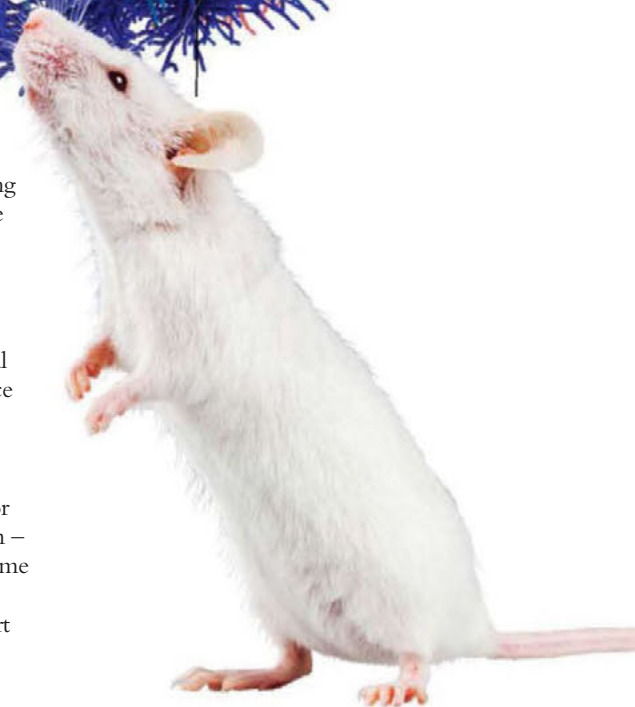


For Shanahan, the more interesting question is whether a digital worm would be conscious. Few people would say that a real *C. elegans* is conscious – it's far too simple to experience its surroundings or suffer – but if the same were to be done for a mammal such as a mouse, you probably would class it as conscious, he says.

"If a simulation of a mouse's brain was embodied in a virtual body, or particularly in a real body, we might be tempted to say that it was conscious," says Shanahan. "If the kinds of signals that come from sensory neurones and go to motor neurones are pretty much the same, and it exhibits the kind of behaviour you would expect, I would find it very difficult to see how you could justify saying that it wasn't conscious in so far as a real mouse is conscious."

Winfield is keen that we start to have discussions surrounding the ethics of creating such digital animals. He sees little difference between a simulated mouse in a computer and one that has been embodied outside a computer. "People might have a stronger reaction to something that's in a physical body, especially if it somehow mimics a real animal, but actually there's no real difference in terms of concern over whether it experiences suffering."

The OpenWorm team is concentrating on making a useful model in a computer for scientists, and don't intend to make a worm – or a mouse – with a real-world body any time soon. But their efforts to recreate a tiny worm in a computer are getting to the heart of some of the biggest questions in artificial intelligence today. ■



THE EXISTENCE OF BLACK HOLES

BY BRIAN CLEGG

Fiction depicts black holes as yawning voids that lurk in deep space, gobbling up any planets in their path. The idea of 'dark stars' dates back to the 18th Century, but it was 1964 before hard evidence emerged

Black holes have escaped from astrophysics into the everyday imagination. Yet the gaps in our knowledge of their nature and even, possibly, their existence are considerable.

Black holes were born from theory, not observation. We have known about conventional stars for as long as we've been able to look up at a clear night sky. But no one ever saw a black hole. Instead, they were predicted to exist at a time when there was no way of checking whether there was any such thing out there. And that prediction happened not once, but twice.

The first inspired thinking on the matter was back in the 18th Century. The man who dreamed up what he called 'dark stars' was John Michell, a Cambridge scientist who later became a clergyman. It was from his rectory that he came up with the concept, combining two key ideas of the latest science at the time.

One was escape velocity. Michell knew that when a bullet is shot straight up into the air, it has just two forces acting on it once it leaves the gun – air resistance and gravity. As it gets higher, both of these forces weaken. The air gets thinner and, as

Newton had made clear, gravity's attraction drops off with the square of the distance between the centres of the bodies involved – in this case, the bullet and the Earth.

A typical bullet from the black powder guns of Michell's day could travel as fast as



Ole Rømer calculated a speed for light, settling the dispute over whether it travelled instantly, or just very quickly

300 metres per second. But despite this impressive velocity, the forces acting to slow it brought the bullet back down to Earth. Michell, though, knew that a bullet travelling about 37 times faster would be able to overcome the Earth's attraction and fly off into space. It would have achieved escape velocity. He combined this idea with a discovery from the 1670s, when Danish astronomer Ole Rømer realised that an apparent variation in the timing of Jupiter's moons was caused by the varying time that light took to reach us from the planet.

Light conversation

Ever since ancient times, there had been arguments over whether light travelled instantly, or just extremely quickly. Rømer found evidence for a measurable speed, as the changing relative positions of Jupiter and Earth in their orbits varied the time that light took to reach us. He calculated light's speed to be around 220,000km/s. In the following 100 years, this figure was measured more accurately so that Michell was working with something closer to our current 300,000km/s. But the





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Computer rendering of a
supermassive black hole. Jets
of matter are emitted at right
angles to the accretion disc

> IN A NUTSHELL

Studying black holes is particularly difficult as they cannot be seen directly. The work of eminent scientists like Albert Einstein, Kip Thorne and Stephen Hawking has helped increase our understanding, but many gaps in our knowledge still remain to this day.



Michell was working with something closer to our current 300,000km/s. But the specific value didn't matter – the point was that light had a speed.

Combining the two concepts of escape velocity and light having a finite speed, Michell wondered what would happen if a massive star had an escape velocity that was above the speed of light. The more mass in a body, the higher its escape velocity. Therefore, in principle, there could be a star so vast that even light would not escape from it. Such a 'dark star' would have to be immense. Even though the escape velocity from the surface of the Sun, for instance, is over 600km/s, it is still far lower than the speed of light.

Michell's theory was based on an incorrect assumption – that light was made

up of normal particles that could be slowed down like any other projectile by the force of gravity. But the idea of these mysterious 'dark stars' faded into history.

Fast-forward to the 20th Century and Karl Schwarzschild revived the theories in the heat and horror of World War One. It was 1915 and the 41-year-old German physicist had volunteered to join up with the German army. Somehow, perhaps as a distraction from the devastation around him, he found time to think about Einstein's elegant equations and his brand new theory of General Relativity. Einstein's equations are too complex to provide a universal solution, but Schwarzschild solved them for the special case of a spherical body that was not spinning.

It emerged from the mathematics that if all the mass of that body was crammed into a sphere of a size now called the Schwarzschild radius, the distortion in space-time would be so great that light from the object would never escape. Anything closer than a sphere around the body of that radius would travel through a surface of no return, the black hole's event horizon.

The most obvious source of such a body would be a collapsing star. In normal operation, a star's nuclear reactions fluff it up against the pull of gravity. But once those reactions start to fade, matter in the star can collapse. The expectation is that this collapse would be halted by a quantum effect called the Pauli exclusion principle, forming an intensely dense neutron star. If

THE KEY EXPERIMENT

Black holes are tricky to study as even the closest one lies many light-years away, but scientists can identify candidates by observing their X-ray emissions

Performing experiments on black holes is a non-starter, as the nearest candidate so far detected is around 3,000 light-years away.

Confirmation of Cygnus X-1, the first significant candidate found, took a number of years as no single observation was capable of establishing such a remarkable find.

In 1964, a rocket launched from the White Sands Range in New Mexico discovered a strong X-ray source in the constellation of Cygnus. Also in 1964, two sub-orbital rockets mapped out X-ray sources, pinning down the location of Cygnus X-1.

In 1971, observations by the Uhuru X-ray satellite telescope showed that the Cygnus X-1 source underwent rapid oscillations, suggesting it was a compact object that was smaller than the Sun. That same year, radio telescope observations linked the X-ray source to the star HDE226868. This blue supergiant would not itself produce X-ray emissions, implying that it had a companion. Also in 1971, astronomers at the Royal Greenwich Observatory and Toronto's David Dunlap Observatory made further observations of HDE226868. They confirmed that it was in a binary with a massive but compact object. And in 1972, Charles Bolton at Toronto was the first to state definitively that this object was a black hole. This view was generally accepted by 1973.



Cygnus X-1 (location outlined in red). In this image, the blue supergiant companion star can be clearly seen to its right

the star were massive enough, though, exceeding about three times the mass of the Sun, the exclusion principle should be overcome and the collapse would be unstoppable. In principle, the material in the black hole would continue to collapse all the way to a dimensionless point – a ‘singularity’ with infinite density and a force of gravity that headed off to infinity as it was approached. In reality, we don’t know what would actually happen, because the singularity is an admission that our physics has broken down.

Down the hole

For a good time after Schwarzschild, black holes were purely theoretical. Or at least collapsed stars were, as they were yet to receive their more intriguing moniker. ‘Black hole’ is often ascribed to the American physicist John Wheeler, but its origins are shrouded in mystery. The term was first reported at an American Association for the Advancement of Science meeting in January 1964. It’s not certain who used it, but Wheeler soon picked up the term and popularised it. It might seem that searching for black holes would be a waste of time. How do you see something that doesn’t give off light? But as the physics of black holes developed, scientists realised that indirect routes were available.

As astronomers can’t see the hole itself, they need to look for its side effects. When matter is dragged into a spinning hole, and pretty well everything in the Universe does spin, it should produce an ‘accretion disc’, glowing brightly as a result of friction, and would also generate distinctive ‘jets’ from the poles. Then there are the gravitational effects. We might see nearby bodies influenced by the black hole. This is a venerable technique, and was used in the past to infer the existence of Neptune. Astronomers studied the way the orbits of the other planets were influenced by Neptune’s gravitational pull.

Finally, there is ‘Hawking radiation’. Stephen Hawking surprised himself as much as anyone else when in 1974 he realised that black holes couldn’t truly be black. The idea came from his understanding of quantum physics – the science governing very small things – and in particular the ‘uncertainty principle’. This said that localised

CAST OF CHARACTERS

Five incredible physicists who have helped us with our understanding of black holes

Karl Schwarzschild
(1873-1916)

Schwarzschild was a German physicist and astronomer who was born in Frankfurt. He worked as a professor for several years in Göttingen, then moved on in 1909 to become director of the town’s observatory before heading up the Potsdam Astrophysical Observatory. He volunteered for the German army in 1914 and died of a skin disease in 1916.



John Michell
(1724-1793)

Michell was born in Nottinghamshire and spent his academic life in Cambridge working on geology, gravity, magnetism and astronomy. After his marriage in 1764 he spent the rest of his life as a clergyman, most notably at Thornhill in Yorkshire. Here he continued with his scientific work from 1767 until his death.



Albert Einstein
(1879-1955)

German-born Einstein is best known for his theories of Special Relativity and General Relativity, laying the foundations of quantum theory. He moved to the USA in 1933 to escape Nazi Germany and took up a position at the Institute of Advanced Study in Princeton.

Kip Thorne
(1940-)

Thorne is an American astrophysicist whose studies of General Relativity have resulted in a wide range of predictions on black holes, wormholes and time travel. Thorne was consultant to the best cinematic representation of a black hole to date, the 2014 movie *Interstellar*.



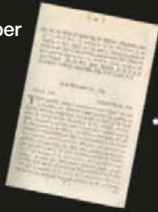
Stephen Hawking
(1942-)

Cambridge-based Hawking is probably the most famous living physicist and has become iconic for his bestselling book *A Brief History Of Time* and for defying the onset of motor neurone disease to continue working into his 70s. His work has largely involved the General Theory of Relativity and cosmology.



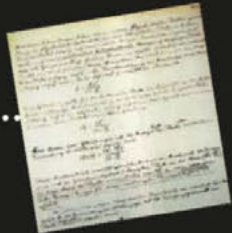
TIMELINE Theories surrounding mysterious black holes have only been around since the 18th Century

John Michell's 'dark stars' paper is read at the Royal Society. Michell hoped to deduce the mass of stars from their effect on light, and thought a massive enough star would be able to stop light entirely.



1783

1915

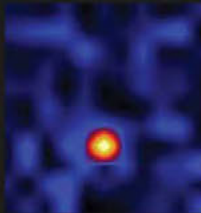


Albert Einstein publishes his field equations. This set of 10 equations at the heart of General Relativity describe gravity as a curvature of space and time.

Soon after Einstein publishes the theory of General Relativity, Karl Schwarzschild publishes his paper with the first non-trivial solution. This is applied to a non-rotating sphere, derived the previous year.

1916

1971



First candidate black hole is found. Cygnus X-1 is an X-ray source that was first detected in 1964 and is thought to be a binary star, where material from one star is accelerated into a black hole.

Star S2 (Source 2) is observed by the Max Planck Institute and UCLA. It orbits an apparent supermassive black hole, Sagittarius A*, at the heart of our Milky Way.



1995

The best evidence to date of a star being ripped apart by a supermassive black hole is detected by the Pan-STARRS telescope on Hawaii and analysed by a Johns Hopkins University team.



2012

➔ energy can fluctuate significantly over small periods of time, allowing pairs of quantum particles to emerge and then disappear again before they are observed. If this happens near a black hole's event horizon, one of these 'virtual' particles could be pulled in while the other flies off. These stray particles make up Hawking radiation. This is unlikely to be detectable at any great distance.

After Schwarzschild's solution, black holes seemed the natural end for the right kind of stars with masses at least three times that of the Sun. But this particular scale is not a limitation of the black hole itself, merely the formation mechanism. In principle, black holes could exist on any scale from the microscopic all the way through to millions of times the mass of the Sun. There are broadly four categories, two of which have probably been detected.

At the tiny, totally hypothetical end of the scale are micro black holes and quantum black holes. A micro black hole would form, for instance, if the Earth collapsed, forming an event horizon about 9mm across, though thankfully there is no known mechanism for this to occur. Quantum black holes are even smaller, from a scale of around 5,000 protons up.

In principle, they could be produced in a particle accelerator and would almost immediately decay. Current accelerators don't have the energy to produce one unaided, but if the Universe has extra dimensions, this could reduce the energy threshold to something accessible.

The best evidence we have for conventional black holes, formed from the collapse of a dying star, is X-ray binaries. In these objects, material is accelerated from one normal star into an invisible star, giving off X-rays. This can happen with a neutron star, but if the 'eating' star has more than about three times the mass of the Sun, it should in theory be a black hole.

The first X-ray binary widely recognised as containing a black hole was Cygnus X-1. A powerful X-ray source was detected in 1964, and was identified as a black hole candidate in 1971. A blue supergiant star in the binary was being stripped of material by the X-ray source, which appeared to have a mass in the

NEED TO KNOW

A handy list of the terminology surrounding black holes

1 ACCRETION DISC

Rotating matter is pulled into a disc shape by a star (part of the formation process of a solar system). In the case of black holes, nearby matter is accelerated intensely by gravity, giving off a bright glow.

2 JET

Streams of matter accelerated to nearly the speed of light are emitted at right angles to the accretion disc. The cause of these jets is uncertain, though they may be the result of a complex magnetic field.

3 PAULI EXCLUSION PRINCIPLE

This principle of quantum mechanics establishes that two fermions (a type of subatomic particle) cannot be in an identical quantum state. This results in 'exchange interaction', which is like a short-range force keeping fermions apart – except in extreme conditions like black hole formation.

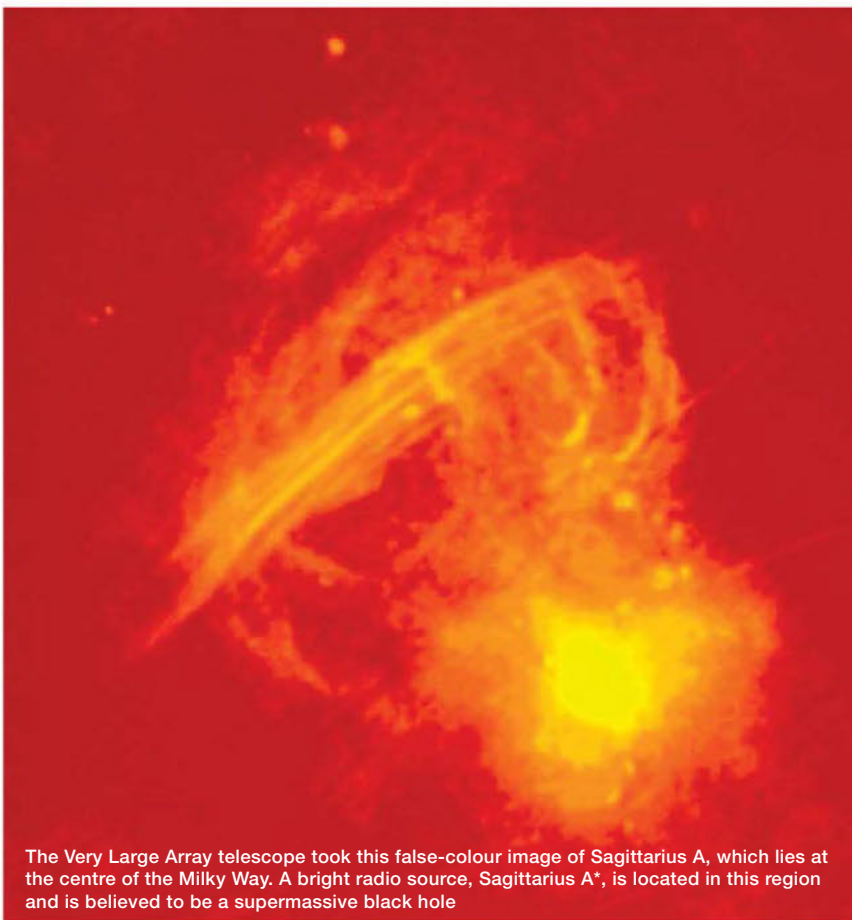
4 SINGULARITY

In the case of astrophysics, a singularity is a mathematically predicted condition where space-time becomes so locally distorted by gravitation that the force of gravity tends to infinity and current theories of physics break down.

region of 9 to 15 times that of the Sun. In 1975, Kip Thorne and Stephen Hawking made a bet as to whether this was, indeed, a black hole. Hawking, on the 'no' side, paid up in 1990 when better observational data was obtained.

Back to black

Since 1990, the identification of Cygnus X-1 has become less certain. This is because the companion star is very large, which makes it difficult to be sure of the mass of its 'compact object' companion.



The Very Large Array telescope took this false-colour image of Sagittarius A, which lies at the centre of the Milky Way. A bright radio source, Sagittarius A*, is located in this region and is believed to be a supermassive black hole

Many other candidates have been detected since, although evidence remains indirect and is based on theoretical assumptions about the maximum size of a neutron star that may not be borne out in practice.

Supermassive black holes are thought to exist at the heart of most galaxies, possibly forming from the collapse of a dense gas cloud in the galaxy's early life. Such black holes may play a significant role in galaxy formation, giving the galaxy a hub to coalesce around. Candidates have been detected at many galactic centres, thanks to unusually high electromagnetic emissions from these regions, and the odd motion of nearby stars.

A star called S2 orbits the centre of the Milky Way at about four times the radius of the orbit of Neptune. From S2's path, it seems likely that it's orbiting something with a mass of about 4.3 million times that of the Sun. The object matches the position of an intense radio source called

Sagittarius A*, and there is currently no other explanation for this except a supermassive black hole. Elsewhere, stellar destruction gives a clue. Unusually bright light signatures in distant galaxies are thought to be stars being ripped apart by supermassive black holes.

All is not certain, though. A 2014 study suggested that black holes won't form at all. The authors suggest that as a star collapses, Hawking radiation during the collapse would reduce the mass of the star sufficiently that the black hole never reaches completion. There would be an ultra-dense body acting like a black hole, but without the singularity or the event horizon. The paper is not universally accepted, but illustrates how our understanding of black holes is primarily driven by theory. Whatever the reality, we can expect more surprises.

BRIAN CLEGG is author of many science books, including *Science For Life: A Manual For Better Living and Gravity: Why What Goes Up, Must Come Down*

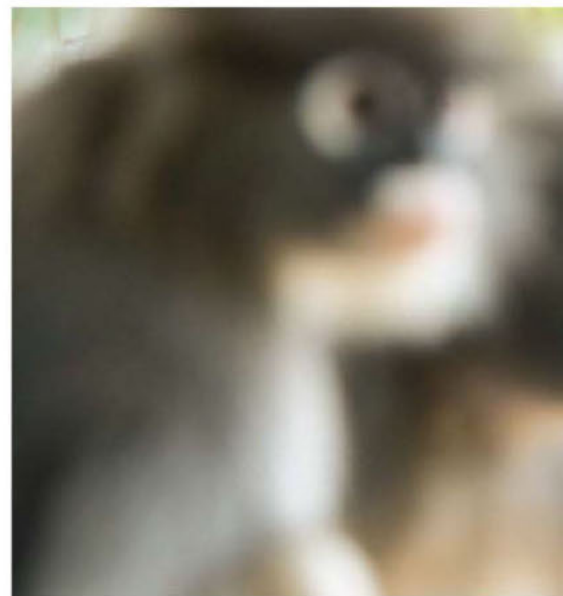
There are seven subspecies of dusky leaf monkey *Trachypithecus obscurus* found across Burma, Malaysia and Thailand, where this group was photographed. Outside of Khao Sam Roi Yot National Park, the animals face multiple threats including illegal hunting and habitat loss. They are listed as Near Threatened on the IUCN's Red List

Leaf monkey *magic*

Dusky leaf monkeys have evolved to exploit a niche diet in the canopy of South-East Asia's forests. But these adaptations could also make them a target for the illegal wildlife trade, says primate scientist **Dr Dirk Meyer**



Like many Old World monkeys these langurs have a sacculated or chambered stomach, as well as special bacteria, to enable them to break down their mainly leaf-based diet. They spread their foraging through the day so they don't overload the digestive processes that help them to remove plant toxins and digest leaf matter





FAR LEFT After eating, young monkeys spend a lot of their time playing. Aggression is rare and when it does occur they are quick to make up, sometimes within a matter of minutes. Reconciliation often involves a mixture of social grooming and chest-to-chest hugging

LEFT Also known as spectacled langurs, these primates are characterised by large rings around their eyes and mouth. The size and shape of these markings allow researchers to identify individuals within groups, but they are shy and not easy to observe for any length of time



Evolution plays some strange tricks. It has equipped a select group of primates with a ruminant-like, multi-chambered stomach that allows them to digest a diet of leaves and unripe fruit. For dusky leaf monkeys this could be the very reason they are so highly prized by hunters.

“We conducted a survey with local people in Myanmar who said that these monkeys are delicious, particularly the stomach,” says primatologist Dr Dirk Meyer. “Their bones are also used in traditional Chinese medicine.”

He is currently in Myanmar (Burma), collecting samples from faecal matter and leeches. “Genetic material in the leeches’ gastro-intestinal tracts remains in a useful condition for a long time, so it’s possible to verify the existence of species that are difficult to observe,” he explains. “Using a combination of these samples and recordings of primate vocalisations we hope to get insights into their genetic relatedness.” Dusky leaf monkeys are a diverse group with seven subspecies, and Meyer believes this research could be an opportunity to classify one of them as a species in its own right.

Finding these elusive monkeys, and the samples they leave on a leaf-strewn forest floor, is a real challenge. “They are a difficult group to study,” explains Meyer. “They’ve been hunted for hundreds of years and shyness has been fixed in their genes, which makes them difficult to approach or observe for more than a few minutes.”

The dusky leaf monkeys in these photos are from a national park in Thailand. Though much of that country’s rainforest has been lost, in neighbouring Myanmar large areas still remain. The country’s growing political openness has sparked rapid deforestation driven by the expansion of palm oil production, which represents a threat to many species in this area. 🐼

PHOTOS BY

STEFANO UNTERTHINER



Stefano is a zoologist and photographer who specialises in projects that put him in close contact with a species for a long period of time. He has a strong commitment to wildlife conservation and environmental issues, particularly the interactions between people and animals. His latest book is about Italy’s Gran Paradiso National Park.

www.stefanounterthiner.com

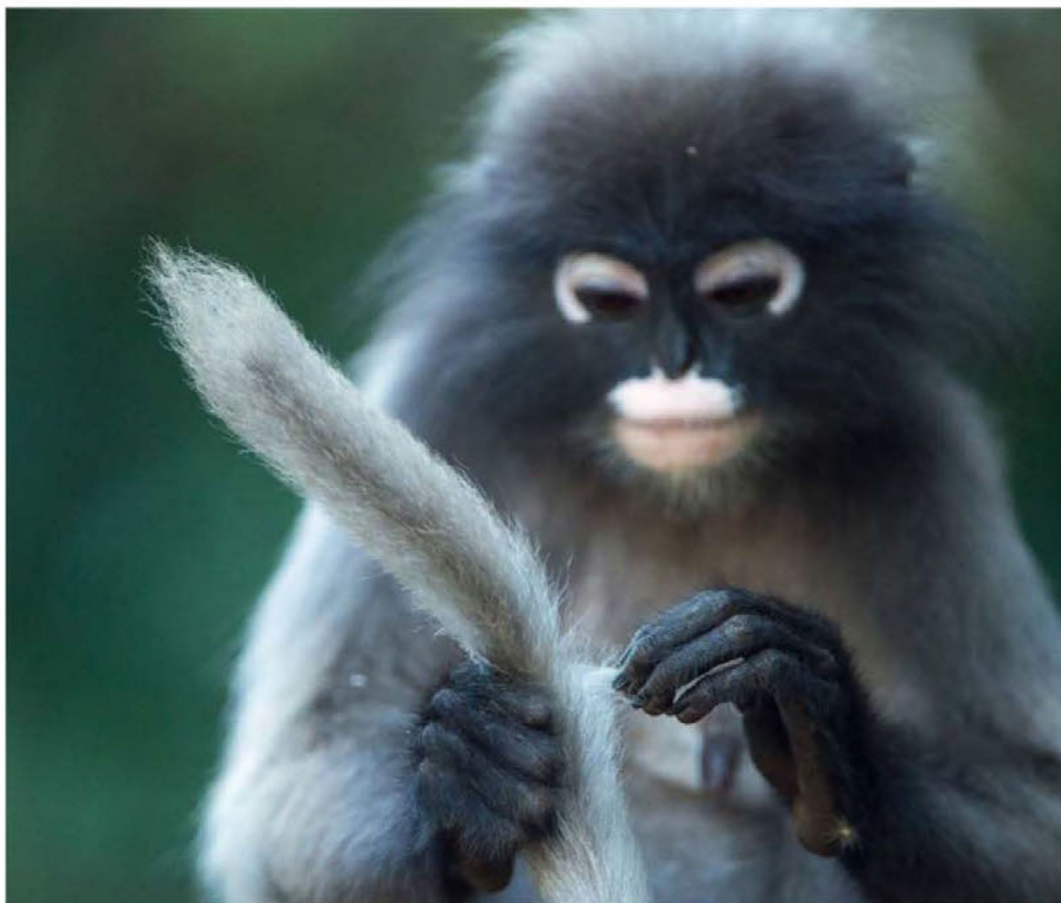


THE LOCATION

KHAO SAM ROI YOT NP
Established in 1996, this was Thailand’s first coastal national park and the name translates to “the mountain with 300 peaks”. It is a haven for wildlife with more than 300 bird species. The park is a mixture of limestone mountains and marshland, as well as relatively inaccessible forest areas which hold the dusky leaf monkey, crab-eating macaque, slow loris, Malayan pangolin and the Thai fishing cat.

Dusky leaf monkeys are capable of breeding throughout the year. They give birth to a single offspring, which spends most of its first three weeks suckling and sleeping. After this time they begin to develop their motor skills through play jumping. At this stage the mother will also encourage independence by increasingly biting and pushing the infant away





ABOVE During the day a troop will split up and forage in smaller groups that then come back together again in the evening. When they find a tree with edible fruit on it they will include that in their daily patrol until the food has been exhausted. Locations like this limestone rock are a good place for researchers to look for faecal samples

LEFT Young monkeys begin social grooming at around 70 days old. This is an important part of reinforcing bonds between individuals in the group. Other forms of tactile communication include hugging and 'bottom holding', where one individual will hold the hindquarters of another to communicate dominance



ABOVE Young monkeys are often transferred from one female to another. A single female may watch up to four infants at a time, allowing others in the group to rest, forage and feed. By the time infants are eight months old they are increasingly distant from their mother

RIGHT Dusky leaf monkeys spend most of their time in the canopy. Though their diet is mostly leaves, they also eat flowers and unripe fruits, using the same digestive adaptations required to break down plant toxins. The ability to consume food other species can't digest allows for a more sedentary lifestyle





A newborn has bright orange fur, which begins to darken at around one month old. The reason for this striking difference between adult and infant is unknown, but it could provide a signal to all of the members of the group that this individual requires extra care and attention



LEFT Dusky leaf monkey troops have a defined territory that rarely overlaps with other groups, which may be a reason why conflict is so rare. The males maintain their home range through their 'territorial honk', which can be heard most in the morning and is often accompanied by an arboreal display

QUESTIONS AT THE FRONTIERS OF...

ASTROPHYSICS

The Universe is not only vast, it may not be the only one. That's just one of the cosmic mysteries that astronomers would love to solve, says **Prof Ian Morison**

Q What's inside a black hole?

In August 1975 a massive X-ray flare was observed in the constellation Monoceros, but only a very approximate position could be obtained. Using radio telescopes at the Jodrell Bank Observatory, my colleagues and I were able to find a precise location, where the only object that could be seen was a star a little smaller than our Sun. It was in a binary with an unseen object and their combined mass was calculated to be roughly 10 solar masses. Thus, the companion had to have a mass greater than nine solar masses – much more than the four solar mass threshold above which a black hole would form.

In Einstein's theory of General Relativity, the mass of such an object warps the space around it so tightly that it curves in on itself allowing nothing to escape – not even light. It also predicts that all the mass that forms the black hole will exist in a singularity, having zero size and infinite density. Singularities tend to arise when theories are inadequate to describe what exists. We know that somehow Einstein's classical theories of gravity must be combined with quantum mechanics – the theory used to describe the behaviour of particles smaller than atoms. So relativity itself can almost certainly not predict what happens at the heart of a black hole. The theory that will be quantum gravity – but it has still to be formulated.

If not infinitely small, I suspect that the size of the condensed mass at the centre

of the black hole would still be incredibly small. As mass contracts down under gravity to form a black hole, the nucleons (subatomic particles found in an atom's nucleus) will break down into even smaller particles called quarks. What size might this clump of quarks be? The 'diameter' of a quark is suspected to be about 1,000 times less than that of a neutron. A simple calculation based on the known diameter of a neutron star gives a diameter of about 0.04mm. This could, perhaps, be what resides at a black hole's heart but without a formulated theory of quantum gravity, we may never know.

Q Are we alone in the Galaxy?

Given the number of stars in our Milky Way, many of which we now know to have planetary systems, it used to be thought that intelligent life would be very common. Now, astronomers are not so sure.

It may well be that simple life is quite common and we could even find evidence of its existence in our Solar System. For example, 'burps' of methane recently discovered above the surface of Mars led some to suggest that it could be a sign of microbial activity.

Observing planets in other solar systems using infrared light has already detected the presence of water vapour in the atmosphere of a Neptune-sized planet. Although water is a probable requirement for life, this does not mean that life is present. Should ozone

be detected, however, it would indicate the presence of free oxygen. As water vapour and oxygen are highly reactive, they cannot exist for long without being replenished and would thus indicate that plant life was present.

While I suspect that single-celled life may well be quite common across the Milky Way, astrobiologists have recently come to the conclusion that the transition from





Artist's impression of a black hole surrounded by a disc of matter
Inset: NASA computer simulation showing a shredded star being sucked into a black hole

single-celled to multi-celled organisms is a highly unlikely event. Even when it does occur, a planet has to then keep a temperate climate on its surface for several billion years to allow intelligent life to evolve. Our large Moon has stabilised our rotation axis and the tides it produces may have helped life to transfer from the oceans to land. Earth could well be, as some have argued, a very rare planet. As a result, many

astronomers now suspect that we may well be the only intelligent beings in the Galaxy.

Our only way of knowing if others exist is to detect an intelligent signal from them. The most sensitive search to date took place from the late 1990s and involved the world's largest radio telescope at Arecibo in Puerto Rico along with the UK's Lovell Telescope. The study searched star systems within about 200 light-years – a tiny

fraction of the Milky Way, which is 100,000 light-years across.

In the next decade, a giant radio telescope is scheduled to be built in South Africa. The Square Kilometre Array will greatly extend the search area, but unless intelligent life is very common, it is still unlikely to be detected. I suspect that intelligent life is very rare and believe that, sadly, we will never know if we are alone.

Q Do we live in just one of many universes?

Our universe is just one of a vast (perhaps infinite) number of universes, according to a cosmological theory called 'string theory'. And there is one piece of evidence that suggests this might be true. It is simply that our Universe is able to support life. In a book entitled *Just Six Numbers*, Astronomer Royal Martin Rees points out that if a number of physical parameters were not very close to their observed values, life could not exist. As there is nothing in the laws of physics to define their values, there seem to be only two possibilities. Either our single Universe was created specifically so that life could exist, or some universes in what is termed a 'multiverse' will, by chance, have the right properties – our Universe being one of them. The individual universes may well co-exist in a further spatial dimension at the same time.

Will we ever know? Perhaps an analogy can help. Suppose three slices of bread are suspended side by side from a knitting needle and a few ants are placed on the right side of each slice. If they could reason, they would perhaps think that they lived on a two-dimensional world and would have no idea that the other worlds existed nearby. As humans are able to comprehend objects in a three-dimensional space, we can understand that the ants all co-exist in a further dimension of space.

In early 2010, I wrote in the description of a lecture "...perhaps we live in a multiverse that extends beyond our imagination". I was implying that our human minds (certainly mine) may be incapable of comprehending the totality of the cosmos or the fundamental laws that govern it. In an article the following summer, Rees also made the same observation. Sadly, this may be one mystery that will never be solved. ■

PROF IAN MORISON previously served as the Gresham Professor of Astronomy. His latest book is *A Journey Through The Universe*

SURVIVAL OF THE FITTEST

Cars are evolving. Today, they need to be cleaner, safer and smarter.
Daniel Bennett tests the vehicles that are shaping motoring's future



PHOTO: ADAM GASSON

THE CAR THAT... MAKES HYBRIDS DESIRABLE **BMW i8**

Sat in the car park of BMW's UK headquarters, where we picked it up, the i8 looks like it belongs in a different decade from the cars surrounding it. Unlike most concept cars, its futuristic features have made it to the factory floor – so it still has gull-wing doors that open upwards, it has wings at the rear that channel air over the body and it still has those blue

paint details signifying the battery under the hood. The Philip K Dick aesthetics though, beautiful as they are, are the least exciting thing about it.

Underneath the i8's bonnet there's a 129bhp electric motor that powers the front wheels. Meanwhile in the back, right behind the cockpit is a 228bhp, impossibly small (1.5-litre) petrol engine sending power to the rear wheels.

Somewhere in the back there's also a third tiny electric motor that helps recharge the lithium battery. Of course, all of this equipment is quite heavy, so BMW

has made the doors and passenger cell out of a new composite material – carbon fibre reinforced plastic – which is 30 per cent lighter than aluminium. This cocktail means that the BMW can be frugal with your fuel when you want it to be (BMW says it can get up to 134mpg, though we averaged a laudable 40mpg). But flick the gear lever down into Sport mode, and this combination has another use: speed.

At the flick of a switch, the instrument cluster flashes red and the petrol engine snarls behind you. This in itself is not surprising, but what

happens next is. The petrol motor throws all of its grunt into spinning the rear wheels, while the electric motor hauls you forward. All petrol engines will have an optimum power range, a spectrum in the rev counter where they run most efficiently. Outside of this range the power delivery drops off sharply, but in the i8 the electric engine simply fills in the gaps, hurling you forwards with almost brutal acceleration. There is nothing quite like it.

But even that's not what really won us over about the i8. Although this is a red-blooded sports car, its low

CO₂ emissions (49g/km) mean it's exempt from road tax as well as London's Congestion Charge. It's also eligible for the government's plug-in car subsidy. So this car (insurance aside) won't kill your wallet after you've bought it. In fact, most of the time, since the UK's average journey length is under seven miles, you could in theory just potter around town and hardly spend a penny, using its 37km (23-mile) EV range. It's a money-saving combo that's proven so popular that owners can now sell the car for double the price they originally bought it for.

BMW i8
bmw.com





Mercedes-Benz S 350
mercedes.com

THE CAR THAT... CAN DRIVE BETTER THAN YOU **MERCEDES S-CLASS**

A few hours into driving the S-Class, I was rendered immobile by London's pesky traffic. I'd thought the capital's roads might be quiet at 11pm; I was wrong. Still, it seemed like a good chance to poke and prod some of the S-Class's features. Twenty minutes later, I was enjoying an 'activating hot stone massage' from my seat, and I had 'ionized' the air, cleaning it of any contaminants. Bliss!

During the hour that I sat in traffic, it became clear that it was probably easier to list the features the car didn't have than the ones it did. For instance, while the cup holders will keep your drinks cool or warm, they won't cook a Pot Noodle. And while they have thought to fit a fridge in between the rear seats, there's no bar to store your 30-year-old single malt. How naïve. In all seriousness though, there are few

vehicles on four wheels better equipped than the S-Class, and that's not just because of all the luxuries it offers.

Once the traffic dissolved, I got onto the A40 and flicked on the 'distronic' mode. The car's cameras took over the driving, guiding the vehicle between the white lines, blinking on the night vision on the dashboard whenever a pedestrian looked like they might cross the road. No one stepped

out, fortunately, but the distraction meant I had begun to steer into the next lane. Just as the passenger side wheels grazed the white lines, the S-Class took over the controls, slowing the left wheels to pull me back into the lane before gently asking if I might need a rest. Maybe I did.

Nearer my destination in Amersham, I swapped the motorway for narrow country lanes, where I met a deer and its fawn idling in

the road. Thanks to the enormous beam from the Merc's adaptive LEDs, their eyes gleamed at me in the dark. But the night vision had already flicked again to warn me of the hazard ahead.

By the end of my time with the Mercedes S-Class, I wasn't quite sure whether I had driven more miles or the car had. Either way, it's only a matter of time before I'm happy to hand over the controls for good.

THE CAR THAT... *IMPROVES WITH AGE* **TESLA MODEL S**

When the Tesla landed on UK shores last year, it blew us away. This pioneer proved that using batteries to power your car didn't have to mean sacrifice. The 355km (240-mile) range won't suit every driver, but it's plenty for most. Indeed, this time around we got to use Tesla's new supercharger network, and once we'd parked up and plugged in, it only took half an hour to top up. But in the time since our first drive, the car's power train has become its least interesting aspect.

The most amazing feat of the Tesla is how it has evolved over time. Normally a petrol or diesel car stays the same once it's left the showroom, but the Model S is different. The car is riddled with computers, and every part of the vehicle is connected to them. This means that Tesla's engineers are able to send upgrades through the air via the car's 3G connection. These updates download while the car's parked up at night, so when you get back into your Model

S the next morning, it's got even better.

And these updates are more than superficial. For example, the last update added automatic emergency braking to the car – so that the Model S will stop if it detects you're about to slam into something. There was also a Valet Mode added in the last update that tames the Tesla's performance to make sure anyone else driving it behaves themselves. Best of all, some tweaking of the car's algorithms actually made the Model S faster,

shaving 0.1 seconds off its 0–60mph time.

Even more exciting is what's to come. The next update promises to teach the car to drive itself on motorways, and come running when you 'summon' it from the garage. Both hint that the car is nearing the point where it'll soon be able to drive itself entirely – its creator, Elon Musk, just has to wait for the law to catch up with his technology. And it begs the question: why can't all our cars be upgradeable in this way?



The Model S is packed full of innovative tech



Tesla superchargers can juice up the car in half an hour

THE CAR THAT... REMOVES DISTRACTIONS **AUDI TT**



Keep your eyes forward with the virtual cockpit

From the outside this diminutive sports car looks like just that – a featherweight car that'll be as light on features as it is on the scales. But the TT's appearance belies what is an incredibly clever little machine.

The trouble with the cars we've mentioned so far is that, with all of their incredible features, they can be a little distracting. Doubly so, since most of these options are accessed via a central console that's lower than the

windscreen you actually should be looking at. Audi has remedied this with what it's calling a 'virtual cockpit'.

What this means is that behind the steering wheel sits an LCD screen that's the motoring equivalent of an iPad. For example, when you hit the Sat-Nav button, the speedo and rev counter retreat to the sides, presenting a wonderful detailed map. You can flick through your media and all the car's different options

and features, without ever fully diverting your attention from the road ahead. You never feel like you're dicing with death at 100kph just because you wanted to turn the air conditioning down.

It's also the small touches that make a big difference. For example, the dash is perfectly carved out to match the steering wheel, so no information is obscured by the wheel. The buttons are sparse but well placed, so you don't have to look

away from the road to find them. For example, the car's temperature can be adjusted via the fans themselves. Another smart touch is the jogwheel which has a touch-sensitive surface so you can scrawl out addresses and contacts with your fingers. These might seem like small things, but as I drove across Bristol, I soon realised that this was the best designed interior I had ever driven in.

THE CAR THAT... *COULD CLEAN UP OUR CITIES* **TOYOTA i-ROAD**

As ingenious as the previous cars were, they won't make a dent in one of motoring's biggest problems: congestion. Cars are choking the world's cities and the prognosis isn't pretty. A 2014 study by the Centre for Economics and Business Research calculated that British motorists spend four days a year sat in traffic, and that over the next 15 years congestion will cost the UK £300bn.

Toyota is trying to come up with a solution, and this is its latest attempt: the i-Road. Think of it as a motorised Boris bike with a 60km/h top speed and a 48km range. The idea is you drive to the city, park up and swap your car for one of these battery-powered trikes. That might not sound great, but the i-Road makes a lot of sense.

Compared to the futuristic exterior, the

interior is reassuringly familiar: there's a steering wheel, indicators and a dashboard. But that's where the similarities end. Steer left or right and the whole body gracefully leans over, like a speed skater shifting their weight into the corner. But unlike ice skaters, there's no risk of falling over. As the front suspension pushes one wheel downwards, gyroscopes and inertial sensors combine to determine just how

far the car can tilt. The actual steering is done by the rear wheel, which means the back swings round when you want to make a tighter angle. It all sounds, well, slightly mad, but it took all of three minutes weaving through the streets of Grenoble (the only place in Europe you can drive one) for us to fall in love.

Imagine an entire city filled with cars like the i-Road. Traffic would all but disappear, smog would clear and

the streets would be blissfully quiet. This is exactly what they're testing in Grenoble, where you can rent the car for 3 for 15 minutes and 1 for every quarter-hour after. Sadly the i-Road is still only a concept car right now, and as much as we'd love to see Bristol buzzing with little i-Roads, they're unlikely to reach here any time soon. But Toyota has said it's committed to the idea, so watch this space.

**Toyota
i-Road**
Toyota.com



DANIEL BENNETT is reviews editor of *Focus* magazine

BEYOND THE IPOD

Daniel Bennett finds out if the new high-resolution audio players really do sound much better

The iPod has a lot to answer for. It sold us all on the MP3, and in the 14 years since its inception it's all but killed the CD. This wasn't such a bad thing, but somewhere along the way we stopped caring about the quality of our music. Whether we were chasing faster downloads or squeezing ever more albums onto our personal media players (iPods or otherwise), digital music became more compressed, with the audio quality diminishing along the way. That might all be about to change. Weary of the low-resolution MP3s typically sold by the likes of Google Play Music and iTunes, the music industry has started to fight back. Jay Z has just bought Tidal, which is a new streaming service dedicated to high-resolution audio. And then there's Neil Young, the Rock and Roll Hall of Fame inductee,

who is launching Pono in the UK this month. This music store and handheld media player is all about high-resolution albums. Young and other musicians want their music to sound the way they want it to.

PLUGGING IN

From the front, the triangular Pono looks rather like a simplified iPod, but thankfully it sounds nothing like it. When we listened to it in a noisy hall at the CES tech convention in Las Vegas,

a remastered copy of John Coltrane's live version of 'My Favorite Things' (192kHz/24-bit) came to life. For an instant it felt like a stage had popped up in front of us and the bustling crowds of the show had fallen



Astell & Kern AK240
£2,199



Pono
From US\$399

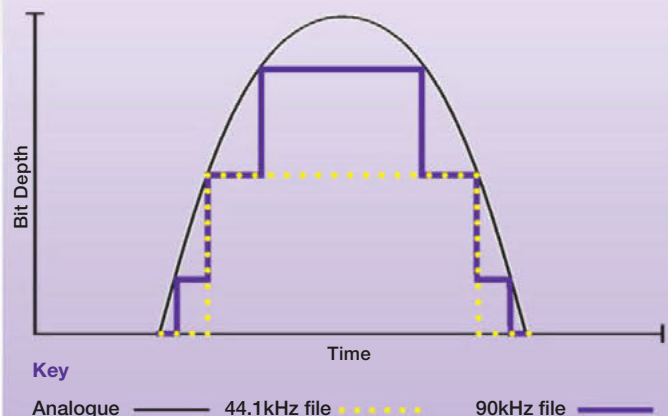


Rock legend Neil Young's Pono has its own PonoMusic store, where users can download high-resolution music. Pono claims to be the "next best thing to live music"

WHAT IS HIGH-RES AUDIO?

Sound is analogue, and it takes the shape of waves. Before CDs, this wasn't a problem since the primary medium for storing and selling music, tapes and vinyl was also analogue. Unfortunately, our current favoured method of storing music, the digital file, is inherently flawed. Digital information is recorded as a binary series of 1s and 0s – on and off. This means it can make an approximation of a wave, but it never truly records it (see graph). It's a bit like trying to build a circle with only flat Lego bricks. A high-resolution audio file does the best job it can by storing as much information as possible, which is why a high-res audio track can be over 10 times larger than an MP3. Meanwhile, a high-resolution media player's job is to decode that information and translate it back into an analogue wave as faithfully as possible.

SAMPLING A SOUND FILE



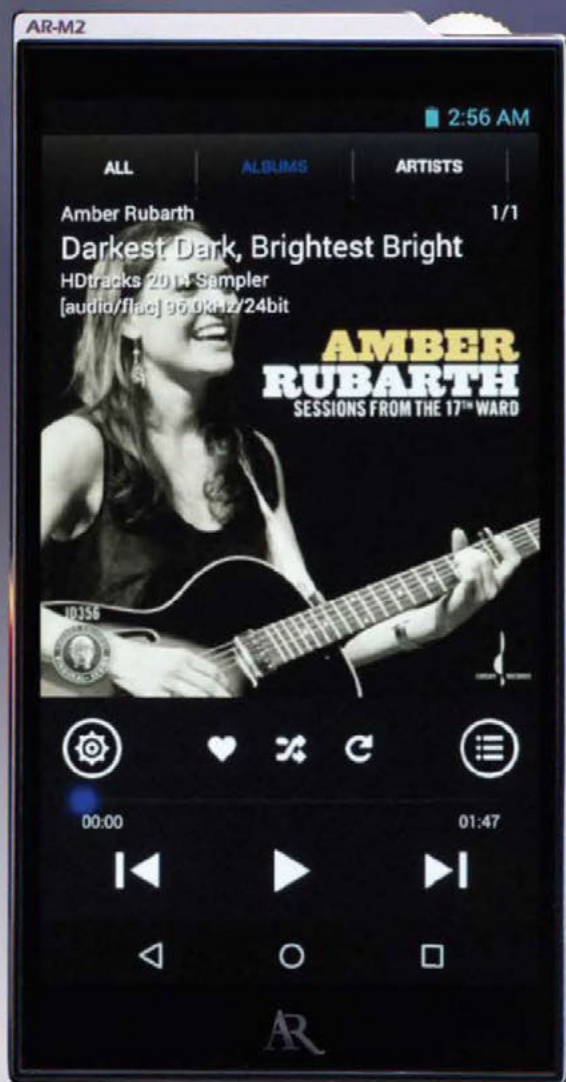
This graph demonstrates how a digital file recreates an analogue sound wave. The higher frequency 90kHz file is a better representation of the original analogue sound produced during recording than the 44.1kHz file.

away. Well, until we looked over our shoulder to find an eager queue of listeners taking shape behind us.

That experience in January left us hankering for more, but sadly there were no samples of the Pono available for us to borrow. Not to be beaten, on our return to the UK we sought out the best new high-resolution media players money can buy: Acoustic Research's M2 and Astell & Kern's AK240. At £900 and £2,199 respectively, these aren't devices you purchase on a whim. But if

you did invest, both are high-tech enough to replace your whole music system.

Everything you need to know about the AK240 is in its price. You're absolutely getting what you pay for. Out of the box it's probably the best-looking media player available on the market. It feels just the right weight, while the sleek gunmetal finish and carbon fibre plating suggest it's built to last – and it had better at that price. As you'd expect, listening to something like The Beatles' White Album



Acoustic Research M2
£900

at 192kHz/24-bit on a pair of Oppo PM-1 headphones (again, some of the best that money can buy), the device is hard to fault, even compared to a dedicated hi-fi setup. But it's actually with some poor-quality files – like an MP3 from the latest Run The Jewels album – where the AK240 impressed most, even when played through some clunky headphones. It's one of the few audiophile devices that doesn't seem too snobby about what you're playing or what equipment you're using

and simply makes the whole listening experience that much better.

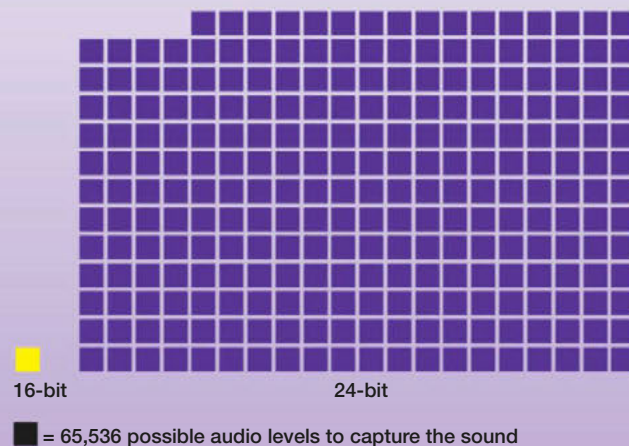
At less than half the price, the M2 certainly isn't half the product. Okay, it might not be as nicely put together and we do have some reservations about its size. But its engineers tell us it has to be that big just to fit all of its technology and components inside. Again, it'll play every music file worth having, and is powerful enough to drive most headphones, even the bigger headphones you use

AUDIO FILES EXPLAINED

High-resolution audio can be recorded in dozens of file types, but Apple Lossless and FLAC are the two most common. The type you choose will be dictated by what you want to play it on, but for audio quality there are two pieces of data you need to look for.

The first is the frequency or the sample rate. This relates to how many times per second the music is being digitally captured. To go back to the Lego analogy (see previous page), the more bricks you've got the more convincing your circle is. The sample rate is usually measured in kHz. A CD comes in at 44.1kHz, or 44,100 slices per second. The second piece of information is the bit depth. At each point where information is captured (where the digital line meets the analogue line in the graph on p83), more or less information about the audio can be stored. So 16-bit audio means that 65,536 possible sound levels can be recorded, whereas 24-bit can record 16,777,216 sound levels – 256 times the possible resolution. The bigger the sample rate and the bit depth, the larger the file will be. When buying high-res music, accept a sample rate no lower than 44.1kHz, and a bit depth no lower than 16-bit. Pono is working to offer most of its library at 192kHz/24-bit.

16-BIT VERSUS 24-BIT



at home that tend to require dedicated amplifiers. A favourite album, Grizzly Bear's *Shields*, was an absolute treat to listen to, revealing fresh nuances along the way. Of course that's bound to happen with £900 worth of equipment, but it's the scope of the sound that impressed us. By giving the bass and treble more texture, it felt like we'd suddenly taken off the blinders and were able to see the whole picture.

Whether it's a US\$399 Pono, or devices that cost three or seven

times as much, it's hard to see how anyone would regret switching to high-res audio. To a newcomer, the gains between each device would be marginal, but once high-resolution audio sucks you in it's easy to see why people start to climb the fidelity ladder. And with streaming services like Tidal, and more artists increasingly selling their music on their own sites at the highest quality, there's little excuse not to listen to your music exactly how it was meant to be heard. ■

QA

YOUR QUESTIONS ANSWERED BY OUR EXPERT PANEL



SUSAN BLACKMORE

Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*



DR ALASTAIR GUNN

Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester



ROBERT MATTHEWS

After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University



GARETH MITCHELL

Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service



LUIS VILLAZON

Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

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Q How much of the electromagnetic spectrum does the Sun emit?

A The Sun emits radiation right across the electromagnetic spectrum, from extremely high-energy X-rays to ultra-long-wavelength radio waves, and everything in-between. The peak of this emission occurs in the visible portion of the spectrum. Different wavelengths of light generally come from different regions of the Sun's atmosphere or are due to particular atoms radiating at specific wavelengths (spectral emission lines). Visible light, for example, comes from the photosphere (or surface) whereas most

infrared light comes from the lower chromosphere just above. Much of the high-energy UV and X-ray photons come from the Sun's outer atmosphere (called the corona). This gives astronomers the ability to explore different solar features, constituents or processes simply by selecting a particular wavelength of light to observe. That is why NASA's Solar Dynamics Observatory, for example, has an array of instruments that cover a wide range of wavelengths simultaneously. **AG**

NASA's Solar Dynamics Observatory can show the range of wavelengths that the Sun emits

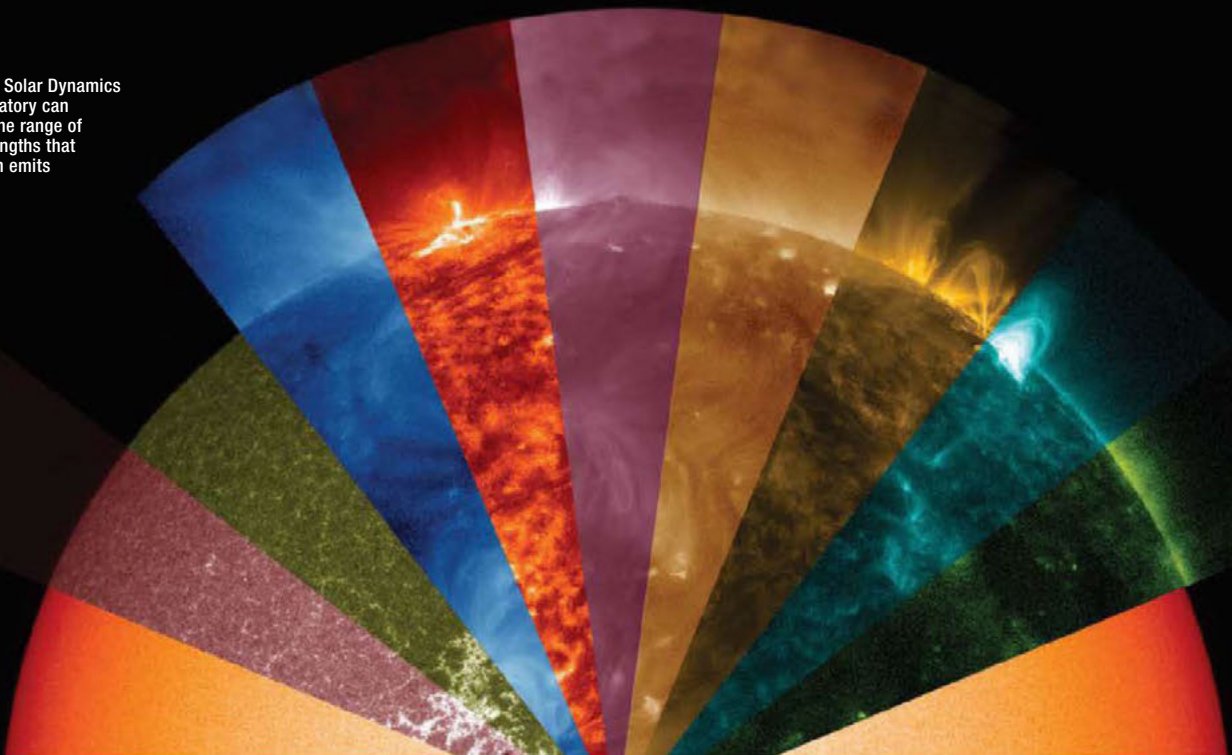


PHOTO: NASA/SOHO

In Numbers

307

kilometres is how far a team sent quantum keys, which are used to encode messages. This beat the previous record of 150km

Q

Why do we close our eyes when we're trying to remember things?

A To avoid distraction. When we imagine something, our brains use the same systems they use for seeing, touching or listening. If you're trying to recall a past event, you need to free up the visual cortex to conjure up the images.

Researchers asked people to watch a short video and then answer questions about it. Those who closed their eyes or looked at a blank screen remembered more than those who watched a display of nonsense images or heard unfamiliar words. In other tests, they had to recall details from a crime video with their eyes open or closed. They remembered more correctly with their eyes closed. They also recalled sounds from the video better when their eyes were shut. **SB**

Q

Where is the loudest place in the Universe?



Some 80 million trees were flattened following the Tunguska Meteor impact

A

Sound is the movement of a pressure wave through matter. Since space is almost (but not quite) a complete vacuum, sound does not propagate easily through it. However, where matter is denser, such as in the atmospheres of planets, within stars, in gas clouds or in environments surrounding black holes, sound waves are thought to be common.

The 'loudest' sounds in the Universe are the ones carrying most

energy. A rough estimate of the loudness of the Big Bang is about 100dB to 120dB. Although this is near the human ear's pain threshold, it is by no means the loudest thing known to us. It is estimated that the loudest thing on Earth was probably the explosion of the Tunguska Meteor (1908) at about 300dB. Perhaps where planets or black holes collide, or where supernovae explode, there may be sounds more powerful than this. **AG**

Q

How do fossils form?

A When an animal or plant dies, it is usually eaten or rots away. But it occasionally gets buried in the silt on the seabed, on a riverbank or by volcanic ash. This can slow down the decay processes enough that the surrounding sediment has a chance to harden before the organism decays, leaving an imprint of the animal's body – or at least its bones. More rarely, other minerals might percolate into the body tissues and harden to form a positive cast of the animal. Fossils can also be squeezed at great pressure between the layers in the rock, until only a thin carbonised smear of the original tissues is left. **LV**



Fossilisation is rare, but it can provide valuable information for scientists

Q

Why do we get goosebumps when listening to music?

A It's down to the flow of dopamine in the brain's reward pathways. The effect is called 'musical chills' and includes raised heart rate and temperature, dilated pupils, goosebumps and tingling down the spine. Oddly, dopamine peaks several seconds before the goosebumps, perhaps because music tempts us into constantly predicting what is coming next. Goosebumps tend to come when a new instrument or voice enters, or when the volume, key or form shifts. Musical preferences make no difference to susceptibility. Sad music is more effective, but the chills are still experienced as positive. **SB**



Amphibians may be able to detect changes in groundwater prior to earthquakes taking place



Can animals sense an impending earthquake?

Q When an earthquake strikes, different vibrations travel through the ground at different speeds. The Primary (P-wave) vibrations travel about twice as fast as the Secondary (S-wave) vibrations that do most of the actual shaking. P-waves are generally too subtle to be felt by humans, although seismographs will pick them up. But some animals may be able to detect P-waves before the S-waves arrive. This would give them less than two minutes' notice for any quake near enough to affect them.

Stories of snakes leaving their burrows, dogs barking excessively or birds flying in unusual patterns, days or weeks before an earthquake actually takes place are more contentious.

But there may be subtle changes prior to an earthquake that animals are able to detect. A 2011 study at The Open University found that the stresses that build up along earthquake fault lines cause pockets of positive charge to move through the rocks to the surface and will trigger chemical changes in the groundwater. This could have been the reason that toads suddenly left their breeding pond a few days before the earthquake that hit L'Aquila, Italy in 2009. Their pond was 74km away from the earthquake's epicentre.

The positive charge could even affect the electromagnetic fields that bats and birds use for navigation, but we don't have any direct evidence for this yet. **LV**

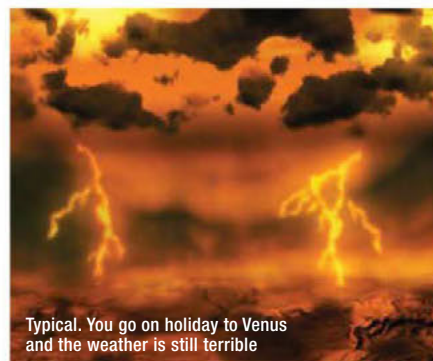


Can fingerprints change during a lifetime?



My, what lovely prints you have!

A The pattern of loops and whorls on your fingerprints was fixed three months before you were born. You can scar your fingerprints with a cut, or temporarily lose them through abrasion, acid or certain skin conditions, but fingerprints lost in this way will grow back within a month. As you age, skin on your fingertips becomes less elastic and the ridges get thicker. This doesn't change your fingerprint, but it's harder to scan or take a print from it. **LV**



Typical. You go on holiday to Venus and the weather is still terrible



Can lightning occur in space?

A Lightning is a sudden electrostatic discharge between regions of differing electric potential. It has been observed on Venus, Jupiter and Saturn, as well as Earth. In space there is little material to act as a conductor of charge. Traditional lightning, therefore, is probably rare. Processes similar to lightning have been observed in electromagnetic fields around black holes as well as in highly ionised clouds of gas and dust called nebulae. **AG**

What is the smallest shark and what does it eat?

A There are several candidates among the dogfish sharks but the smallest is probably the dwarf lantern shark (*Etmopterus perryi*), which is about 21cm long. It lives off the coast of Colombia. Light-emitting organs on its belly attract its prey, which includes small fish and shrimps. **LV**



Daa-dum...
daa-dum...
da-dum da-dum
da-dum da-dum

How do rats survive the toxic gases in sewers?

A The most toxic component of sewer gas is hydrogen sulphide (H₂S), which is produced by bacteria decomposing organic matter in oxygen-starved environments. H₂S is deadly to humans at concentrations as low as 300 parts per million. The lethal concentration for rats is about 1.5 times higher, but they probably just try to avoid gas pockets. H₂S is heavier than air, so it collects in the lowest part of the sewer system. Some humans can detect its rotten egg smell at concentrations of just five parts per billion. **LV**



Did you know?

Twenty people, all over 1.52m tall, crammed into a Smart car in Los Angeles on 20 September 2011

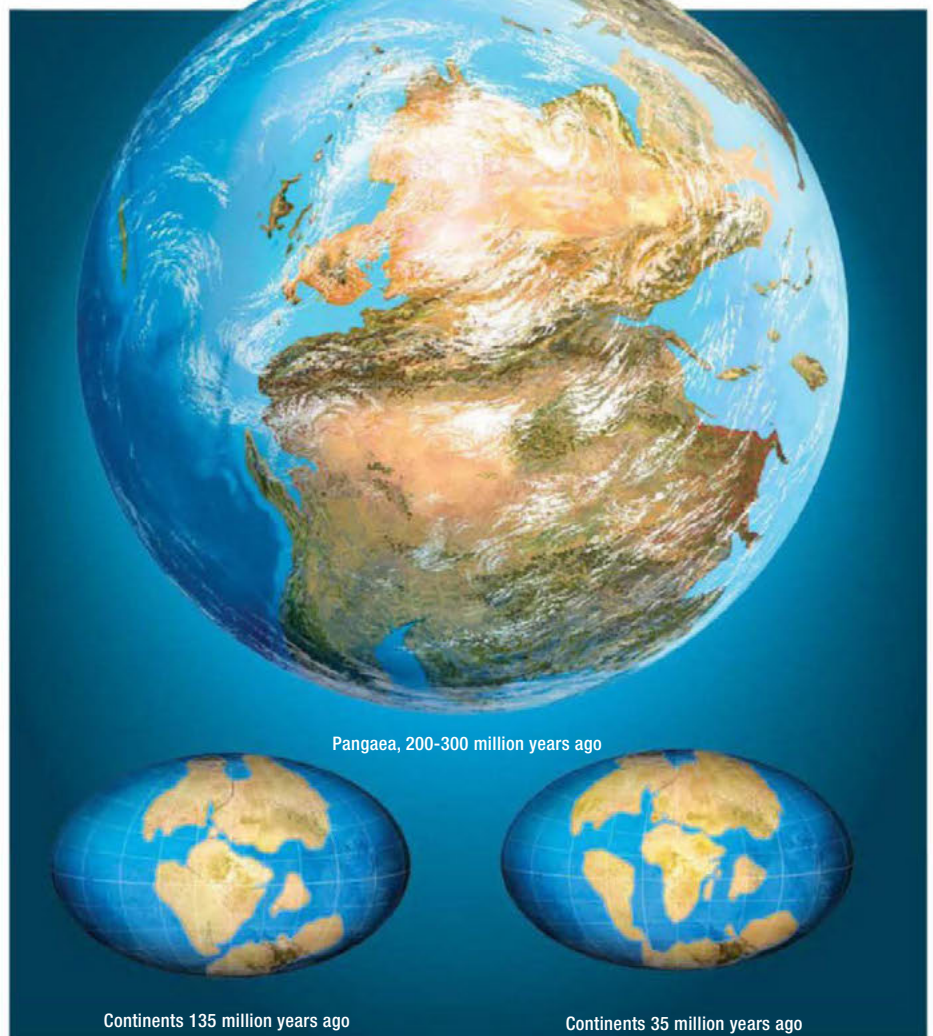


Why is most of the world's landmass in the northern hemisphere?

A The Greek philosopher Aristotle argued that there simply had to be a huge landmass south of the Equator, in order to balance out the vast amount to the north of the planet. The idea of 'Terra Australis' persisted for over 2,000 years and even appeared on maps between the 15th and 18th Centuries. It was finally debunked by Captain James Cook's expedition to find it in the 1770s.

It's now recognised that, despite appearances, the continents aren't that important, being merely slightly thicker parts of the upper crust, which itself represents

barely 1 per cent of the volume of the Earth. Satellite studies of the distribution of gravity across the entire planet reveal little difference between the amount of mass in the northern and southern hemispheres. As such, the arrangement of the world's continents has little significance – and, in any case, has changed over time. Around 200 million years ago, the Earth's surface was dominated by the so-called Pangaea supercontinent, much of which was actually south of the Equator. Pangaea broke up over time to form the modern continents that we are familiar with today. **RM**



Q Where could the next natural disaster strike?

Around the world, catastrophic events are waiting to happen.

Bill McGuire reveals where nature is set to wreak havoc next



JAMAICA, WEST INDIES

KINGSTON



Almost three-quarters of Jamaica's housing is unlikely to survive the violent shaking of a serious quake

The Jamaican capital is no stranger to destructive earthquakes and the threat is once again becoming apparent. Kingston lies on the same fault that spawned the devastating 2010 Haiti quake that claimed 316,000 lives. Seismologists are warning that Jamaica could be next. In 1907, Kingston was battered by a magnitude 6.5 earthquake that destroyed or damaged almost every building and resulted in close to 1,000 deaths. Three centuries earlier, Kingston's predecessor settlement, Port Royal, was obliterated by a magnitude 7.5 quake and resulting tsunami that left little standing and few residents alive. A quake of up to this magnitude is now on the cards again. With close to 75 per cent of the island's buildings described as 'informal', another Caribbean catastrophe could be in the making.

CHILE-ARGENTINA BORDER

LAGUNA DEL MAULE



Everything looks calm from above, but there is gas-rich magma bubbling below the surface

Could the next volcanic super eruption be brewing in South America? The evidence for huge blasts occurring at the Laguna del Maule volcano is clear: its location is marked by a giant, lake-filled crater measuring 25x15km. Over the last seven years or so, the volcano has been swelling at an astonishing rate of up to 25cm a year. This prompted the Volcano Observatory of the Southern Andes to declare a yellow alert in 2013, flagging the possibility of an eruption within months to years.

Recent research suggests that the swelling is linked to an enormous (5x10km) body of rhyolite magma lurking six kilometres or so beneath the surface. Rhyolite is a particularly sticky, gas-rich magma that drives the biggest and most violent volcanic eruptions. A new US\$3m monitoring programme in the area hopes to find out more.

WESTERN UNITED STATES

CALIFORNIA



Racetrack Playa is a well-known dry lake in California. Will the rest of the state soon resemble it?

California is suffering at the hands of a once in a millennium megadrought. Minimal rainfall and a reduced mountain snowpack have led to the driest conditions for at least 1,200 years. In 2015, January – normally the wettest month – was the driest on record, and no rain fell in San Francisco. In the first half of 2014, drought conditions cost the agricultural industry US\$2.2bn and 17,000 jobs. As farmers suck up groundwater to compensate for reduced supplies from reservoirs, 2015 could be even worse as wells start to go dry. The sustainability of the state's food production, which supplies up to half the US's fruit and veg, is being questioned.

BILL MCGUIRE is Emeritus Professor of Geophysical and Climate Hazards at University College London and wrote *Waking The Giant*

TOP TEN PHOBIAS



1= Arachnophobia
Fear of spiders
Incidence: 33 per cent



1= Ophidiophobia
Fear of snakes
Incidence: 33 per cent



3. Astraphobia
Fear of thunder/lightning
Incidence: 15 per cent



4= Trypanophobia
Fear of needles
Incidence: 10 per cent



4= Claustrophobia
Fear of enclosed spaces
Incidence: 10 per cent



6. Odontophobia
Fear of dentists
Incidence: 9 per cent



7. Aviophobia
Fear of flying
Incidence: 7 per cent



8. Acrophobia
Fear of heights
Incidence: 5 per cent



9. Cynophobia
Fear of dogs
Incidence: 3 per cent



10. Agoraphobia
Fear of public spaces
Incidence: 2 per cent

PHOTO: ISTOCK X12, GETTY X2



What's the most amazing result in mathematics?

A popular choice is Euler's Identity, which shows that raising the endless number 'e' (roughly 2.718) to the power of pi, multiplied by the impossible square-root of -1, and then adding the result to 1 produces... zero. How such a crazy mix of numbers leads to such a simple result defies common sense.

No less baffling is the Banach-Tarski Paradox, which shows that a solid ball can be cut into five special shapes and re-assembled to make two exact, perfectly solid replicas of the original ball. Admittedly, the shapes have to be pretty

special – specifically, infinitely jagged, which isn't possible in the real world.

Arguably, the craziest of all results does have real-world implications. It's the sum of all the integers, 1+2+3+4 and so on, all the way to infinity. On the face of it, this must add up to infinity. The correct answer, however, isn't even a positive whole number: it's minus 1/12.

This result emerges from something called analytic continuation of the Riemann zeta function. Physicists have successfully tested its implications in theories about the sub-atomic world. **RM**

$$f(x) = a_0 + \sum_{n=1}^{\infty} \left(a_n \cos \frac{n\pi x}{L} + b_n \sin \frac{n\pi x}{L} \right)$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

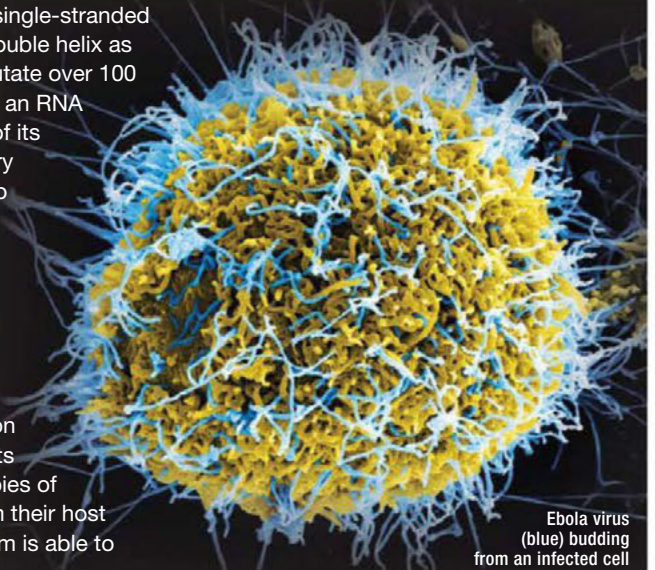
Figure this out, or go to the pub... decisions, decisions



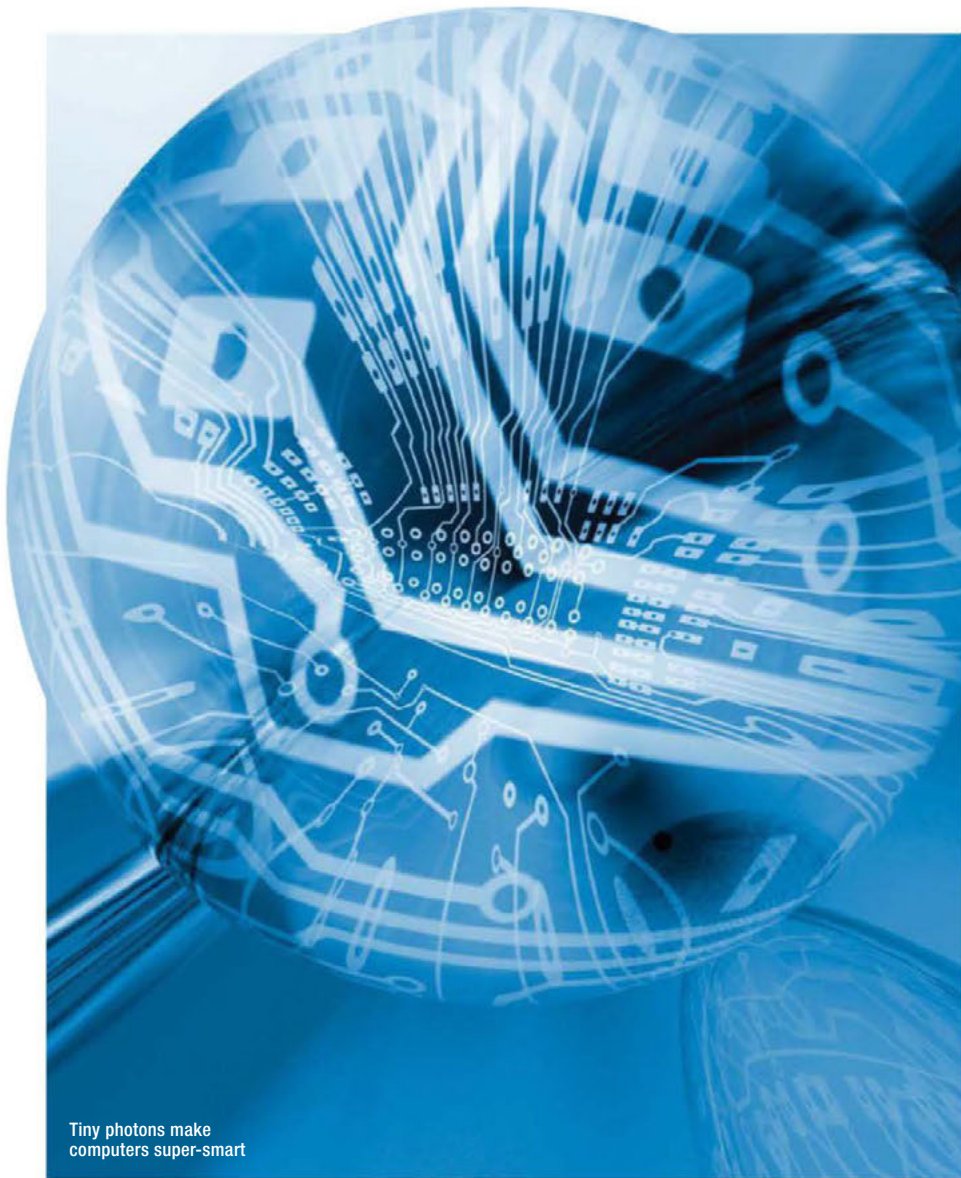
How does a virus mutate so quickly?

Not all viruses do mutate quickly. DNA viruses, like smallpox, have mutation rates that are roughly the same as bacteria and other microorganisms. But viruses that use the single-stranded RNA, instead of DNA's double helix as their genetic material, mutate over 100 times faster. On average, an RNA virus mutates one letter of its genetic code almost every time it replicates. They do this by not proofreading their work. In contrast, DNA-based organisms have special enzymes that spot errors and redo that section of DNA, but RNA viruses lack this. This may be an adaptation to allow them to make lots of hastier, inaccurate copies of themselves to overwhelm their host before the immune system is able to

respond. Most mutations are bad for a virus, so RNA viruses are limited to very small genomes to give them a decent chance of making an error-free copy. **LV**



Ebola virus (blue) budding from an infected cell



Tiny photons make computers super-smart

Q

How does a quantum computer work?

A Quantum computers rely on the characteristic that individual particles such as photons can exist in many places simultaneously. At any one time we only know the probability of the photon being in a given state. So instead of breaking a problem up into 1s and 0s as in a classical computer, we assign it to a quantum computer by priming the initial states of pairs of photons. Each quantum bit – or qubit – is not therefore either 1 or 0, it is both at the same time. A series of qubits represents a range

of values at once and thus a quantum computer performs multiple calculations simultaneously. Unlike a classical computer, we don't get a discrete set of calculations but a series of values that we know to within a certain probability. That might sound rather useless, but problems like decrypting ciphered information are ideally suited to probabilistic computation. Being able to solve many problems at once means that such machines could rapidly break encryption that would be beyond classical computers. **GM**

Q

How long do consoles spend in development?

A Details on the latest consoles, the Xbox One and PS4, are shrouded in secrecy. But generally, it takes three to five years to develop a console. Sony's earlier machine, the PS3, launched in November 2006 after many delays. The first plans were drawn up as far back as 2000, when Sony teamed up with Toshiba and IBM to develop the console's bespoke Cell CPU. Microsoft is a bit faster – the Xbox 360 launched just before Christmas 2005 and began development about three years previously. **GM**



Sony's PS3 took around six years to develop

Q

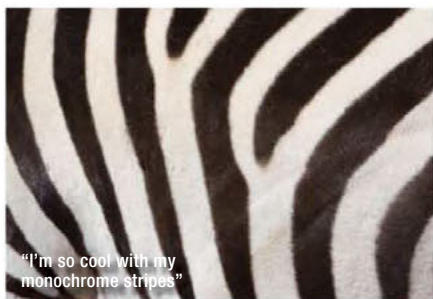
Why does putting a finger down your throat make you vomit?

A Nerves in the roof of your mouth, back of your tongue and throat trigger the pharyngeal or 'gag' reflex if they're touched by anything big enough. Young babies have a gag reflex sensitive enough to be set off by solid food to help protect them from substances that they aren't able to digest. Later, the gag reflex prevents choking but about one in three people don't seem to have a gag reflex at all. **LV**



How did the zebra get its stripes?

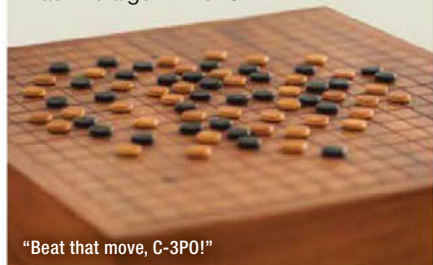
A This mystery has 'finally' been solved many times over the years, with explanations ranging from camouflage to a deterrent against parasites. The most compelling evidence – published this January by scientists in the US – suggests the main benefit comes from the contrasting way that black and white stripes absorb heat. Black gets hotter than white, creating cooling swirls of airflow over the zebra's skin. **RM**



"I'm so cool with my monochrome stripes"

Are there any games at which people can still beat computers?

A Humans still have the edge in the game of Go. Like chess, it's played on a chequered board. But the board has more squares (19x19) and each piece can perform many more potential moves. While chess becomes more computationally straightforward as the game progresses and pieces are removed, Go requires more judgment and intuition. These attributes are more suitable to human intelligence than machine algorithms. **GM**



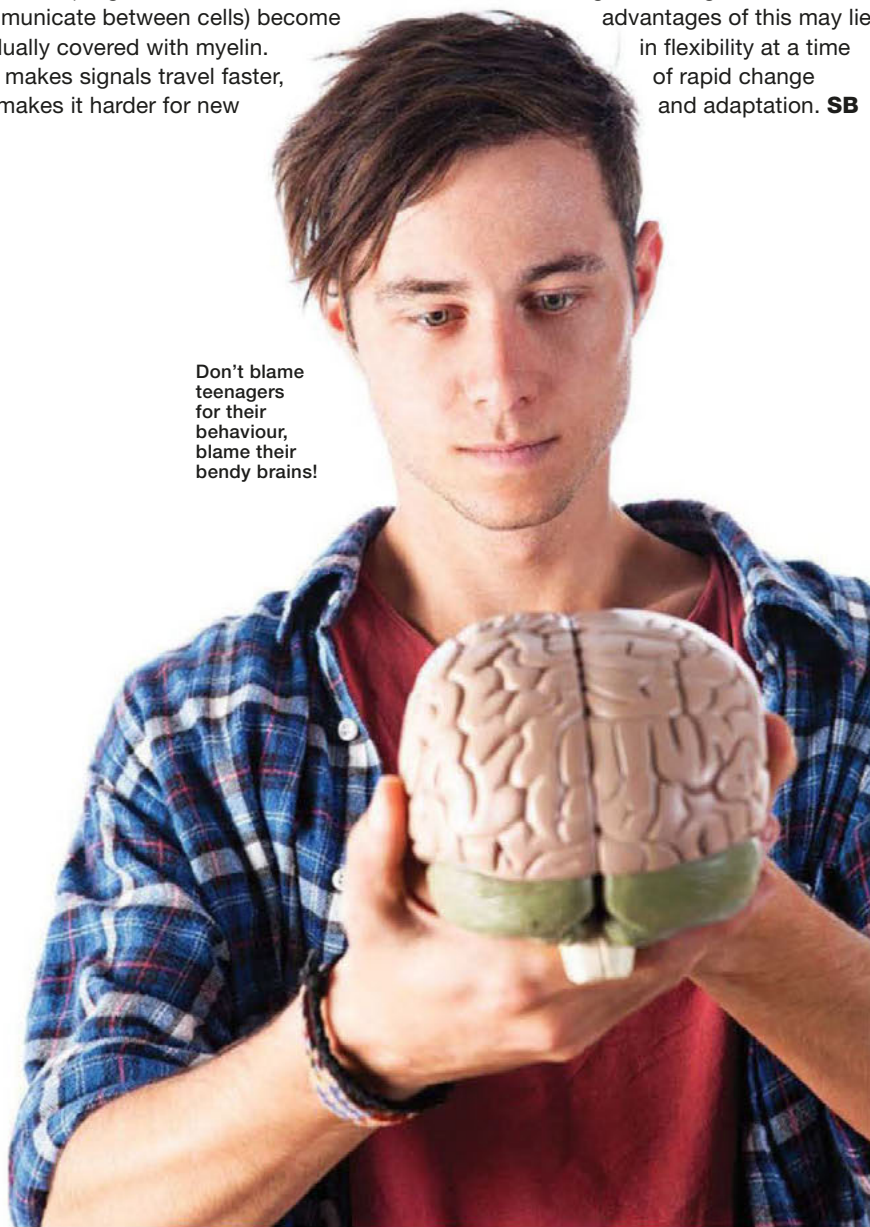
"Beat that move, C-3PO!"

How does a teenage brain differ from an adult brain?

A A teenage brain doesn't grow as fast as a child's, but its organisation keeps changing right up to the early 20s. Synapses in the teen brain are radically pruned, leaving only the most frequently used. The brain's grey matter (cell bodies of neurones) peaks in volume in early adolescence. The axons (long fibres that communicate between cells) become gradually covered with myelin. This makes signals travel faster, but makes it harder for new

synapses to form. In the teenage brain, myelination is not complete so the brain is slower but more flexible. The last parts of the brain to change are the frontal lobes, which are responsible for impulse control and response inhibition. This may explain why teens can be impulsive, easily distracted and poor at setting sensible goals. The advantages of this may lie in flexibility at a time of rapid change and adaptation. **SB**

Don't blame teenagers for their behaviour, blame their bendy brains!



Q What's the difference between an internet meme and a teme?

A Internet memes are created, copied and selected by us. Darwinism claims that when any kind of info is copied, varied and selected then evolution must happen. This information is called a 'replicator'. Genes were the first replicator on Earth, and memes the second. Memes appeared when early humans began to imitate, meaning they could copy, vary and select ideas, skills, stories and technologies. Digital technology may be allowing a third replicator, temes, to emerge – digital info that evolves without intervention. We created

the machinery that makes this possible but are no longer in control of it. This idea may or may not be valid, but it helps us think about the evolution of all that stuff in the web. **SB**



Grumpy Cat disapproves of the Focus Q&A page

Q Why does the human body reject transplanted organs but not blood transfusions?

A Blood transfusions are rejected, if incompatible blood types are mixed. But donated blood is normally centrifuged to separate out the different components. In an ordinary blood transfusion, all you're receiving is the red blood cells. Apart from a few extremely rare cases, everyone's red blood cells fall into four main groups (A, B, AB and O). This makes it much simpler to match donor and recipient – and in emergencies, you can safely give type O negative blood to anyone. Organ tissues have



Dracula's buffet

compatibility types determined by much more complicated genetics with thousands of possible combinations, so finding a good match from unrelated donors is much less likely. **LV**

Q Why is 48 hours' growth of facial hair so uncomfortable?

A Beards grow by about half a millimetre a day. For the first 24 hours, your beard is just climbing back out of the follicles and barely pokes clear of your chin. Once the hairs get a little longer they can rub against nearby skin, particularly under your chin and on your neck where the skin wrinkles up as you move your head. As your beard gets longer, the hairs bend more and are less likely to stab your skin. **LV**



Q Why aren't planes and cars given drag-reducing dimples like golf balls?

A The best way to cut drag depends on the shape of the object. Blunt, round golf balls benefit from dimples because they help wrap the oncoming air smoothly around the ball, reducing turbulence. Sleek objects like planes experience a different type of drag and so wouldn't benefit, but blunter ones like cars just might. **RM**

YOUR QUESTIONS ANSWERED

Q Email to editorial-bbcknowledge@regentmedia.sg. We're sorry, but we cannot reply to questions individually.

B Hardback **P** Paperback

Junk DNA:

A Journey Through The Dark Matter Of The Genome

Nessa Carey

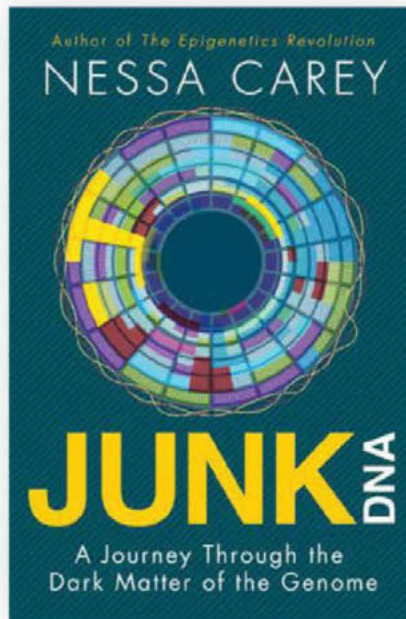
Icon Books **B**

The ‘dark matter’ at the heart of this book is a common fallacy: that as much as 98 per cent of our genetic material is ‘junk’ because it doesn’t code for functioning proteins. So what’s it doing there?

Author Nessa Carey quickly puts this fallacy to bed and gets on with her real objective: a journey through the complex world of genetics. The trouble is, that journey is rather too straight. At times, *Junk DNA* reads rather like a textbook. Most of the chapters include long spells of painstaking explanations punctuated with some hit-and-miss humour and sometimes obscure, occasionally baffling, cultural references.

Genetics is fiendishly complex. “The astonishing triumph is that we understand any of it,” writes Carey. Her explanations are decent, but they are littered with many, many analogies, some stranger than others. One can’t blame the author entirely: genetics, with its machinations and variations, is chock-full of processes so intricate that many scientists and writers have resorted to analogy to explain. Carey’s analogies are supported by functional but uninspiring diagrams straight out of a PowerPoint presentation.

But the real miss here is the lack of characters and story. While genetics is



complicated, it’s full of drama. There are warring scientists, billion-dollar businesses, tragic patients, left-field hypotheses and long-held beliefs (including the titular junk DNA). The book dances around them all but never really brings them to the fore. Diseases are named, but actual patients or scientists lie anonymous on the fringes of each subject. “DNA in a test tube is pretty boring,” writes Carey. It can be on the page, too. While I admire Carey for making the genetics itself the star of the show, with a subject this complex and jargon-filled, relatable characters are sorely missed.

There is some fascinating material here, including the relics of ancient virus invaders left in our DNA. The book also takes a look at the ‘junk’ sequences far away from a gene that can still have a profound effect and the condition that makes you age prematurely. There is a tragic legacy of genetic diseases, and people’s fates are set by the base pairs of their DNA structure.

In sum, *Junk DNA* is not junk – but you have to sift through the bric-a-brac to find the treasures.

MUN KEAT LOOI is a science journalist with a background in genetics. He is co-author of *The Big Questions In Science*

MEET THE AUTHOR



Nessa Carey

If only 2 per cent of our DNA codes for proteins, what is the other 98 per cent – the ‘junk DNA’ – doing?

At one point it was thought that it was mainly just insulation, padding the important bits of our genome so that if cancer-causing mutations happened, they’d hopefully happen in the less vital bits. But we now realise that junk DNA has been co-opted for lots of other purposes, from fundamental things such as making sure that chromosomes don’t unravel at their ends, to more subtle effects. Junk DNA carries out a huge range of functions.

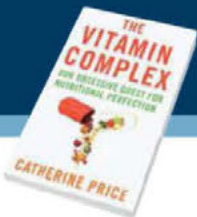
How do scientists investigate the functions of junk DNA?

Lots of conditions are caused by changes in junk DNA, so these have helped us explore what junk DNA does. These include intellectual disability and severe muscle wasting diseases, as well as more benign conditions. Ernest Hemingway had a cat with six toes on its front paws, and there’s a family in the Netherlands where the people have six fingers. Both of these are caused by a single mutation in junk DNA that changes the expression of a key gene involved in hand development.

Given that junk DNA is clearly not junk at all, do you think it’s time we came up with a new name?

It really is. I think one of the problems we face as biologists is that once we give something a name, we tend to get constrained by what that name means, and then we just end up arguing about it. I think if we can come up with a different name, that’d be quite liberating for people’s views on the topic.

“Genetics is full of warring scientists, billion-dollar businesses, tragic patients and long-held beliefs”



The Vitamin Complex

Catherine Price

Oneworld

Catherine Price begins her engaging book about vitamins with the story of William Stark, a young English doctor who decided in 1769 to put himself on a series of incredibly restrictive diets.

He started by eating nothing but bread, water and sugar. After a few months his gums turned black and a “disagreeable, fetid, yellowish fluid” built up in his mouth. He added cheese and honey pudding to his diet, but soon became feverish and bedridden. On 23 February 1770 he died, probably of scurvy, at the age of 29.

Price illustrates that, despite all we have learnt since Stark’s death, when it comes to vitamins and nutrition “we remain surprisingly naïve”. This is particularly true when it comes to vitamin supplements. The fact that vitamin D supplements are often made from lanolin – the greasy substance in wool that keeps sheep dry – was a surprise to me.

The medical consensus is that most of us don’t need to supplement. Yet many people’s diets are so limited that it is only the fact that some processed foods are enriched with artificial vitamins that stops us following Dr Stark’s fate. This book makes a compelling case for the importance of eating real food.

MICHAEL MOSLEY is a BBC science presenter and broadcaster



The New Wild

Fred Pearce

Icon Books

Whether they wash up on islands or hitch a lift in a bird’s gut, alien species have always found ingenious ways to gatecrash ecosystems. Humans have accelerated the process. In this excellent book, Fred Pearce charts everything, including botanists who took plants around the globe and oil tankers that carry marine life in their bilge tanks.

The figure quoted for dealing with ‘alien invasive species’ is an eye watering US\$1.4 trillion. But how is that cost calculated? Pearce takes aim at a raft of statistics and finds they simply don’t stand up to scrutiny. In fact, this book suggests that very few alien species do any real damage: most either die out or end up playing a beneficial part in their adoptive ecosystems. Even some of the worst horror stories, such as cane toads in Australia, actually find their own balance within a relatively short time frame. In an era of climate change, ecological damage and habitat loss, these feisty immigrants might be our best bet of boosting biodiversity. Conservation has a long track record of backing losers, and it might be time to start backing some winners – the very aliens who bring dynamism to struggling ecosystems.

MATT SWAINE is the editor of *BBC Wildlife* and previously worked on *Lonely Planet*



Sex By Numbers

David Spiegelhalter

Profile Books

Sex by number brings to life “the human elements behind the statistics”.

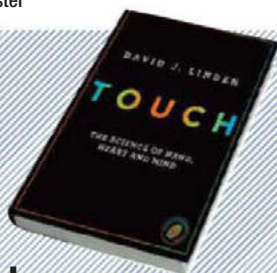
The book teems with eyebrow-raising numbers, which have been verified by the strongest statistical tools in academia’s arsenal. Genetic samples have demonstrated that 1 in 30 people have been unknowingly raised by men who are not their biological fathers. ‘Paternal discrepancy’ – the polite term for cuckolding – accounts for 3.5 per cent of the UK population.

Other stats highlight the ways in which humans view the act itself: 55 per cent of the US population did not think that Bill Clinton ‘had sex’ with Monica Lewinsky. Sex, from this point of view, involves vaginal penetration. By inference, the majority of Americans do not believe that lesbian couples truly ‘have sex’.

Human stories are brought to life too, such as the occasion a gay man met his twin, whom he did not know existed, at a gay bar. Studies of twins raised apart have taught us a great deal about the environmental and genetic factors that influence which gender you prefer.

Are statistics numbers, devoid of personality? Not at all. They just need to be described in the right way.

ZOE CORMIER is a science writer. Her first book is *Sex, Drugs And Rock ‘N’ Roll*



Touch: The Science Of Hand, Heart And Mind

David J Linden

Viking

When neuroscientist David Linden was a teenager, he and his friends sat around a fire asking each other hypothetical questions. One concerned the senses – if you had to live with just one sense, which would you save? Sight and hearing were popular; no one chose touch.

Like Linden’s friends, most of us take the tactile senses for granted. You won’t after reading this book. We learn about the skin receptors and nerve fibres that convey signals to the brain. We also find out how social and emotional context affects the brain’s interpretation of these signals, and

the importance of tactile contact for infant development. Linden investigates conditions that leave people in chronic pain, and the lives of those who feel no pain.

Linden delights in explaining poor technique in terms of the ‘caress sensors’. He also grosses us out with the story of a woman whose itch was so bad she scratched through to her brain. The best science writers infect you with their fascination for the subject – that’s exactly what Linden achieves here.

CHRISTIAN JARRETT is a psychology writer and author of *Great Myths Of The Brain*

HOLLYWOOD SCIENCE

Separating science fact from movie fiction

Immortality in The Age Of Adaline

In this month's film *The Age Of Adaline*, a young woman drives her car into a ditch and becomes immortal. Just like that. But don't go trying it at home. You're as likely to find the secret of eternal youth in a smeggy pond as you are in a jar of face cream.

"In the meantime, the best we can do is aspire to be a naked mole rat or a jellyfish"

Some researchers have speculated that there's no theoretical limit to the human lifespan. Cells may wear out, and genetic mutations and disease build up, but it's nothing that regular trips to the regenerative clinic won't be able to fix. In 2004, Aubrey de Grey, now Chief Scientific Officer at the 'anti-ageing' SENS Research Foundation, speculated that the first person to live to 1,000 was probably already alive. Ageing, he claimed, was a medical condition that would become treatable – a very bold claim indeed.

A decade later, the field is more circumspect. Slashing calories in lab mice and worms has been shown to extend their lifespan. But attempts to reproduce the findings in primates, including us, have proved disappointing. It's just as well, as there's no joy in a life bereft of biscuits. Scientists have moved away from attempting to cure ageing to trying to slow it down. "Researchers are more focused on improving the quality of later life," says Prof Chris Mason from University College London. "It's not necessarily about adding on extra years."

Big, shiny biotech companies like Google's Calico and J Craig Venter's Human Longevity are springing up in the hope of harnessing the power of 'Big Data' to improve our experience of later life. "It's about getting millions of data points from thousands of



people, then crunching all that data together to find the mechanisms in cells that contribute to ageing," says Mason. These could then be targeted with drugs, leading to therapies that will help our ageing cells stay healthy and prevent age-related diseases such as cancer and Alzheimer's. It'll be some time, though, before the findings translate into a clinical product.

In the meantime, the best we can do is aspire to be a naked mole rat or a jellyfish. The naked mole rat, a wrinkly eyesore of a rodent, lives to the grand old age of 30 – five times longer than expected for an animal of its size. Plus, it never gets cancer (no one knows why). The aptly named 'immortal jellyfish' (*Turritopsis dohrnii*), meanwhile, can keep morphing back into a sexually immature version of itself and then grow up all over again. It's the equivalent of you or I flitting endlessly between our adult and prepubescent selves which, come to think of it, isn't such a good idea. ■

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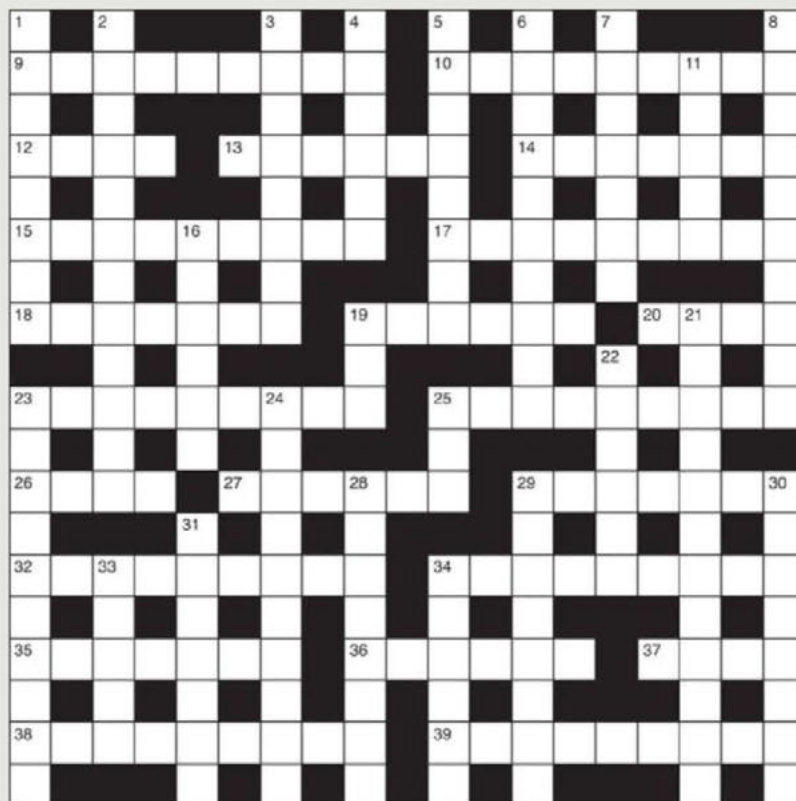
Crossword No.178

ACROSS

- 9 Rose, say, has encountered a gauge (9)
- 10 Like an impossible clue, unable to dissolve (9)
- 12 Basil telephones with deposit (4)
- 13 Effeminate, American place of learning (6)
- 14 Brush off award, getting in shape (7)
- 15 Butterfly to dump fruit for a start (6-3)
- 17 Manage to need my form, finding place to sign (9)
- 18 Deformity, thanks to treatment of piles (7)
- 19 Bird has ends of earthnut in throat (6)
- 20 Talk to a bird (4)
- 23 Eying this new dental assistant (9)
- 25 Porter gets hot running from something that flaps (9)
- 26 Parasites caught in fib (4)
- 27 Town to hold out until morning (6)
- 29 Endlessly respect a novice officer (7)
- 32 Rig Monaco's form of land management (9)
- 34 Deacon and God combine to get into shape (9)
- 35 Asian giant has to be included (7)
- 36 Belief that article is minute (6)
- 37 The burden we bear (4)
- 38 Best not to finish with hesitation by deadline (9)
- 39 Tail pouch designed for oil (9)

DOWN

- 1 Leaving to film a by-product (8)
- 2 Basis of computing fails igloo – no cable (7,5)
- 3 Book about tin sculpture from fabled place (8)
- 4 Happen to find harvest has increased (6)
- 5 Frenchman to insert composition left for singer (8)
- 6 A series on hospital department is harsh (10)
- 7 Send Molly an assumed name (7)
- 10 Bulletin points to landlord (10)
- 11 Hostility about British holy book (5)
- 12 Leave that woman with quiet rodent (6)
- 19 Tug back on the stomach (3)
- 21 Moved to greenhouse of foreign origin (12)
- 24 Class in charge of some acid (6)
- 26 Thus inhale preparation made from plant (10)
- 28 I will find minutia about religious sect (10)
- 29 Resistance unit starts to open his mind (3)
- 30 Both came round to make a sacrifice (8)
- 32 Dane lost location of volcanic rock (8)
- 33 Alight by mistake onto fallen material (8)
- 34 May get confused about defence group's structure (7)
- 38 Right to boot out an automaton (5)
- 40 Woman has peep around foreign port (6)



SOLUTION TO CROSSWORD 175



The Last Word

Economists: dial back the maths and go back to basics

May is my favourite month of the year, as it's pretty much always warm and sunny. That guarantees this May will be rubbish, of course. But if there's one thing worse than a wrong prediction, it's a prediction that proves right for the wrong reason. This leads to misplaced trust.

People have been falling for such predictions for years – 2,600 years, to be exact. In May 585BC the Lydians and the Medes were killing each other, as they had done for years. Suddenly, something startling happened: a cosmic prediction came true.

The Greek philosopher Thales of Miletus had publicly warned that an eclipse of the Sun would darken the heavens, and on 28 May that's exactly what happened. Apparently, it so spooked the commanders of the two armies that they stopped, signed a peace treaty and went home.

Exactly how Thales made his prediction isn't clear. He may have known something about the laws governing eclipses. But some historians suspect he used a dodgy 'rule' that held true at the time, but never worked again. Tellingly, there's no record of Thales repeating his success.

Perhaps we should hail Thales as a pioneer of the art of being right for the wrong reasons. It's an art that flourishes to this day, and nowhere more so than in economics. From the risible attempts to predict inflation rates, to the failure of Nobel prizewinners to spot the global recession even when it was happening, the term 'economic science' is a great oxymoron of our time.

To be fair, what economic science seeks to do is far harder than anything attempted by, say, physicists. Economists try to understand incredibly complex, non-linear systems of interconnected devices known as humans.

Economists use ever more complex maths in the hope that it will bring them the success of 'hard sciences', but this has been their biggest mistake. They've just ended up being wrong much of the time or – worse – they've occasionally been right for the wrong reasons.

Clearly, economics needs a makeover. Here's my proposal. First, and most obviously, dial down the maths: it may look impressive, but too often it conceals dangerous over-simplification. Illustrious economists like John Maynard Keynes, Friedrich Hayek and Hyman Minsky were critical of the 'mathematisation' of the subject. They preferred

“Darwin showed that even earthworms have figured out what economists struggle with: it's impossible to predict the future”



Whether we're talking about economics or eclipses, predictions should be made with care

to capture complex phenomena in words and imagery rather than equations. This was also the approach used by one of the greatest of all real scientists: Charles Darwin. Darwin was a meticulous observer with a genius for spotting telling facts; he created the theory of evolution without the use of heavy maths. Having no numerical ability, he had no choice but to resort to detailed accounts of his ideas, rather than mathematical models.

But economists should do more than merely emulate Darwin's approach: they too should become meticulous observers of the natural world. Darwin showed that even earthworms have figured out what economists struggle with: it's impossible to predict the future. Instead, organisms use diversity to increase their chances of survival. Darwin didn't need fancy maths to prove why diversity works – the success of life on Earth is compelling enough. It's time that economists swapped equations for broad-brush insights drawn from the natural world. If they did, I'm almost willing to predict they'd see their stock rise dramatically. Almost. ■

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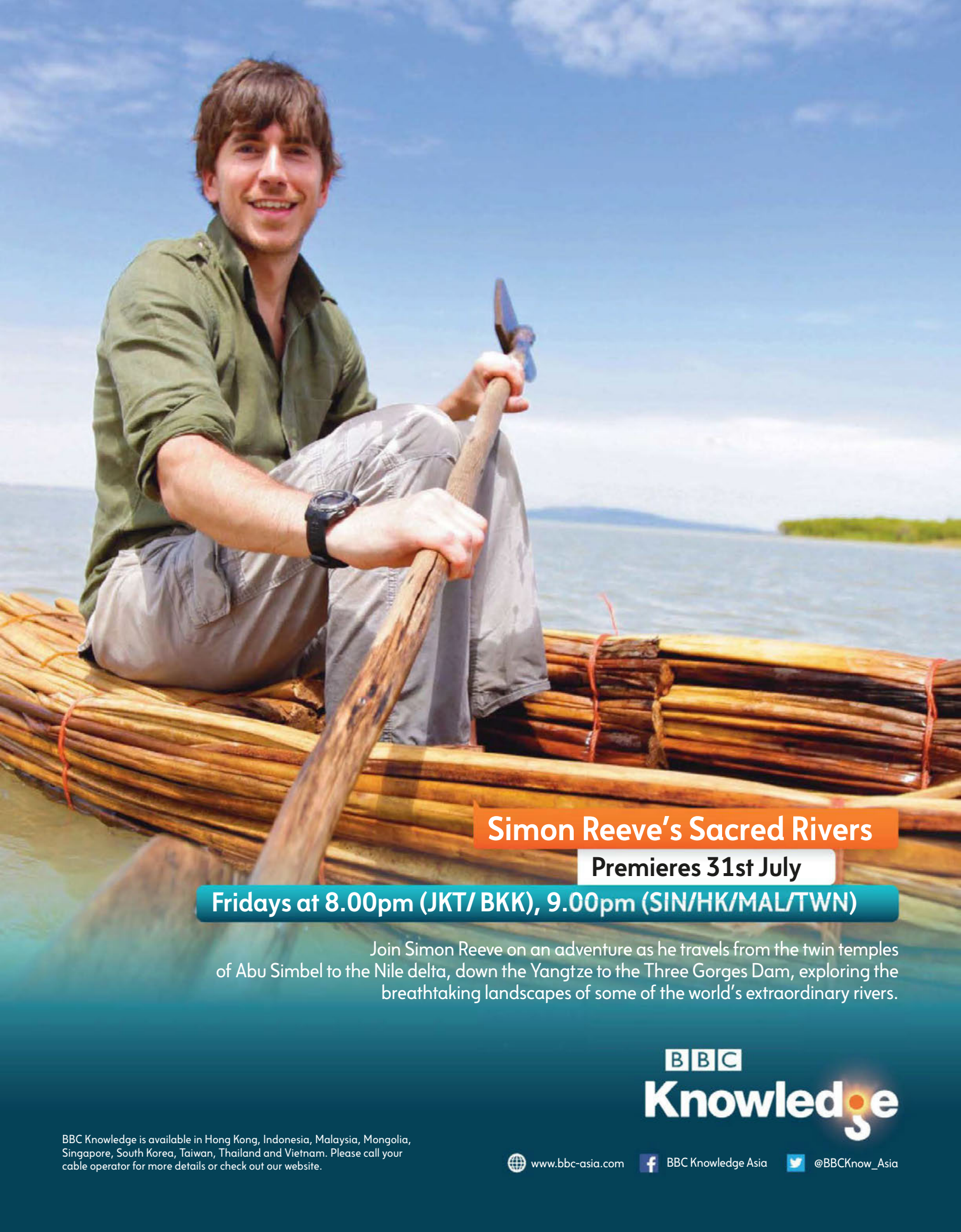
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